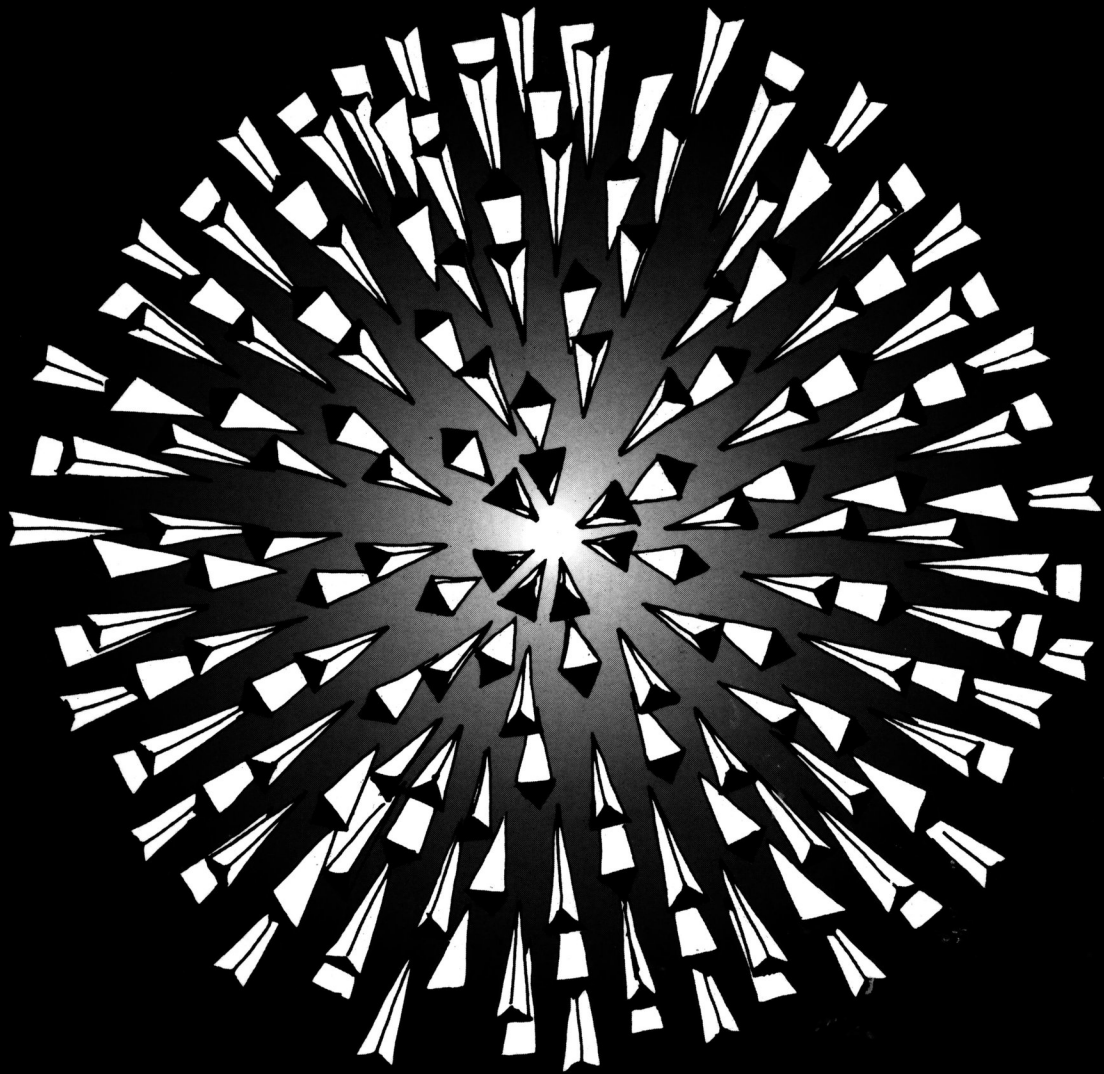


BUCKY

FOR

BEGINNERS

9

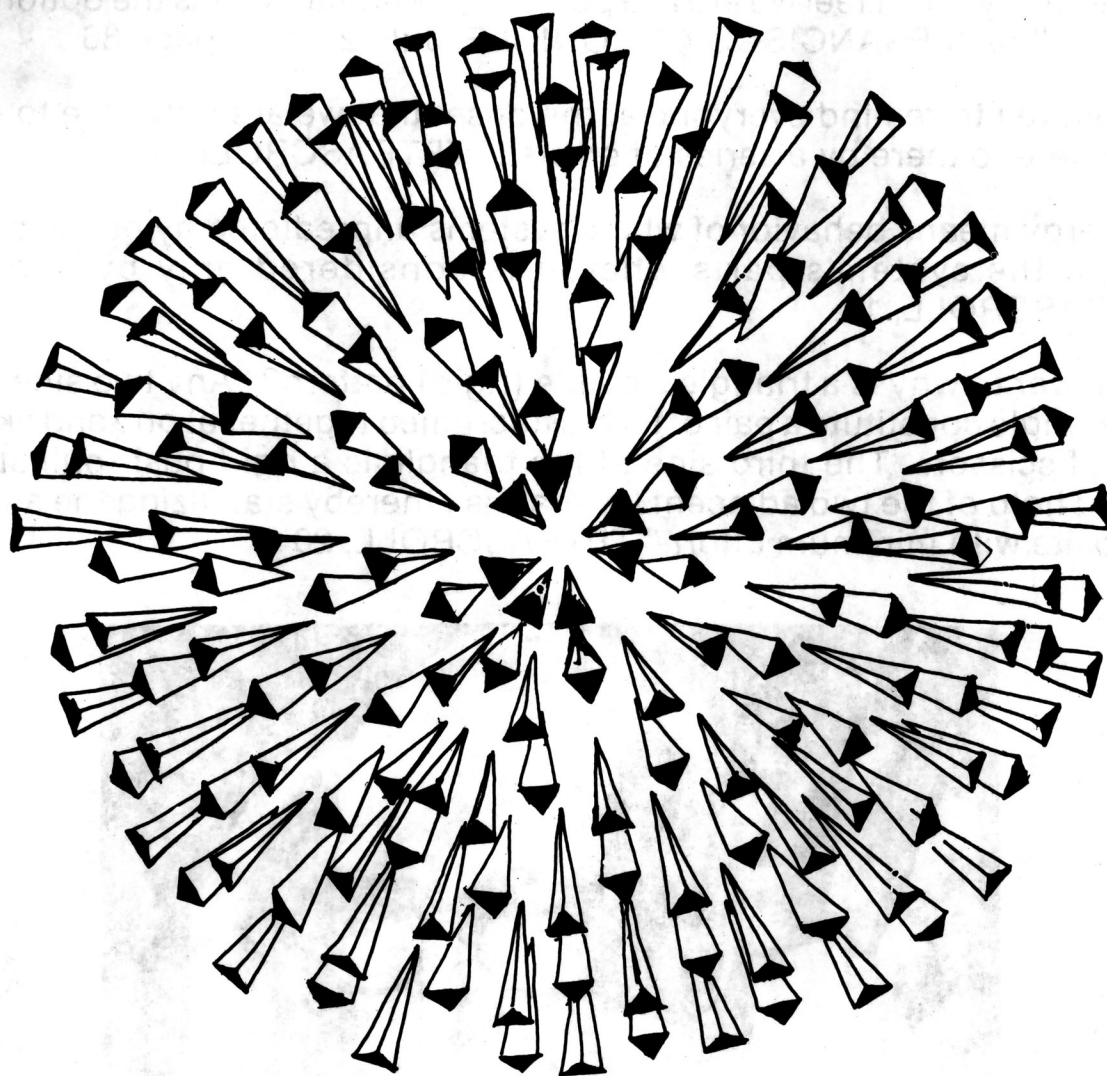


Synergetic

Geometry

Mary Laycock

BUCKY FOR BEGINNERS



SYNERGETIC

Geometry

Mary Laycock

DEDICATION

"There is no death. There is always life in a different variation. He is alive in a different way, but we cannot communicate with him." Bucky, TETRASCROLL, xxv

Buckminster Fuller's ideas will live on in the minds and hearts of young people. The purpose of this book is to promote his living on.

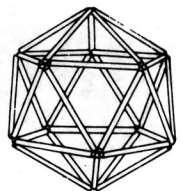
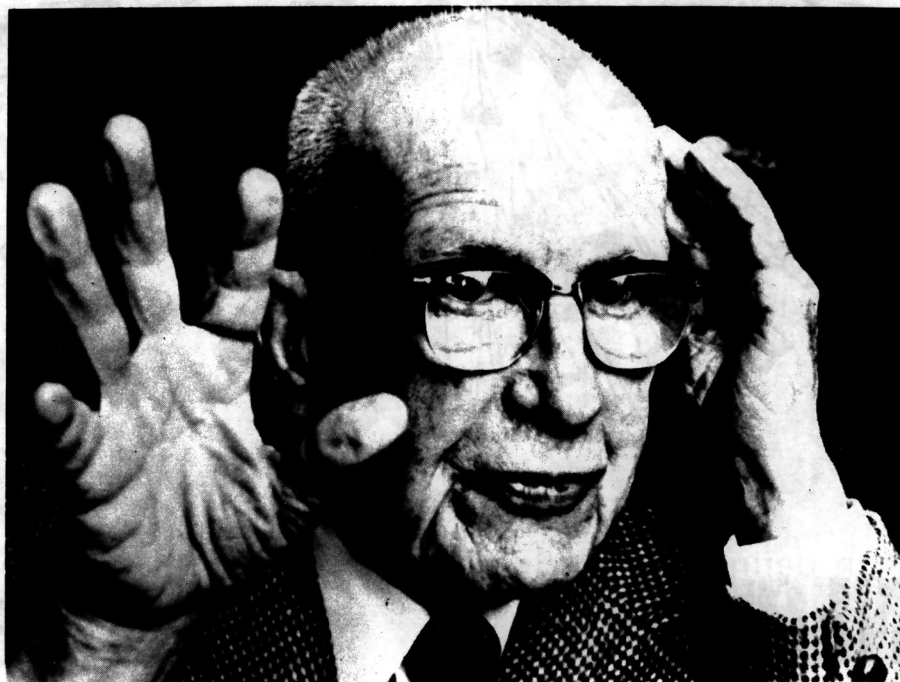
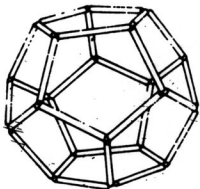
QUOTATIONS FROM BUCKMINSTER FULLER

"We must be here for some extraordinarily important function," he said earlier this year. "I feel we are at a point where humanity has the option to make it." SAN FRANCISCO CHRONICLE, July 2, 1983, page 36.

"...it is well to remind everyone at the onset that we are only able to get from here to there by a series of errors.." TETRASCROLL, xxi

"Synergy means behavior of whole systems unpredicted by behavior of any of the system's parts when it is considered only by itself." TETRASCROLL, 12.

In answer to why is a triangle a stable (rigid) pattern? "Any two sides of the triangle constitute a pair of levers fulcrumed together at one end like a pair of scissors. The third side of the triangle is a rigid push-pull strut taking hold of the two adjacent lever arms.. thereby stabilizing the angle opposite with minimum effort." TETRASCROLL, 20



SYNERGETIC GEOMETRY

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Rather than define a word like "tetra" or "Synergy" before it is used students make something from which they can make the term meaningful.

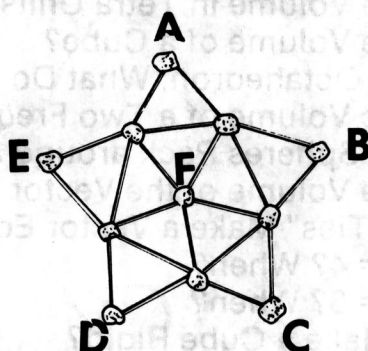
Artist: Martha Kyzer

ACTIVITY 1 MAKE A DOME

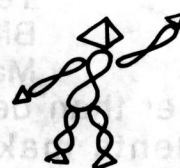
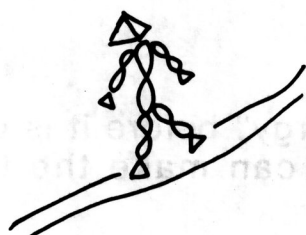
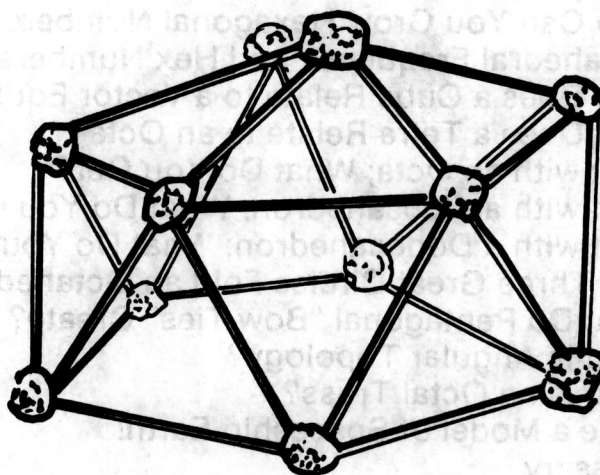
Since most of the world associates the name of Buckminster Fuller with the geodesic dome, make a simple one in his memory. Extend this with what you read about Bucky in other places and make even "fancier" domes than this.

Materials: 12 small gumdrops (or soaked dried peas); 20 toothpicks (preferably colored).

1. Assemble the pattern below: (NOTE: Point F will be above the plane of GHIJK.)



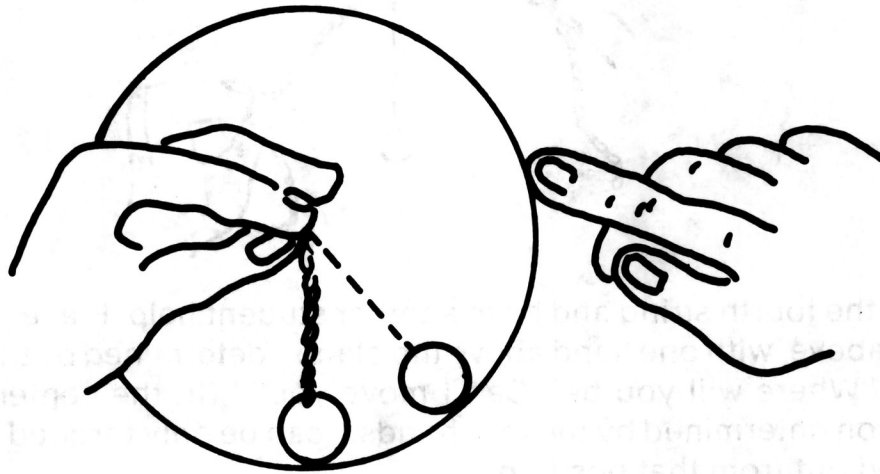
2. Attach another tooth pick from A to B, B to C, C to D, D to E, E to A to make the dome stand.



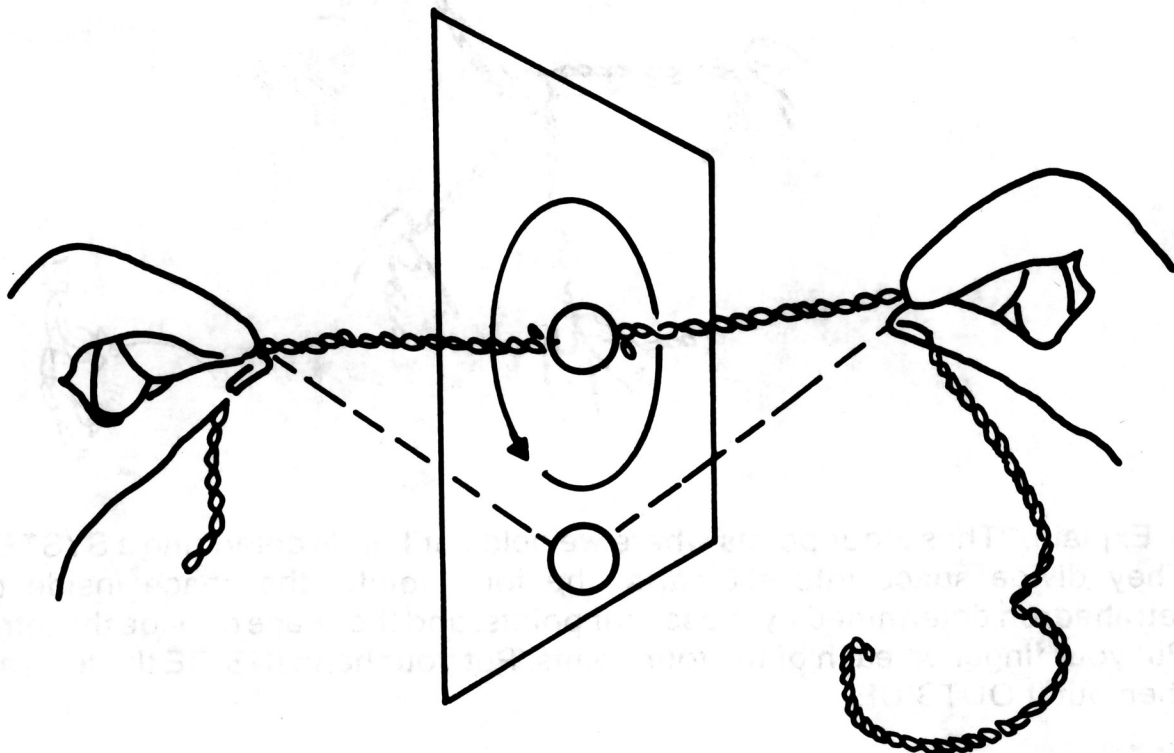
ACTIVITY 2 WHAT IS A SYSTEM?

Materials: One small metal ring; four pieces of string about 50 centimeters long; skill in creating a FANTASY!

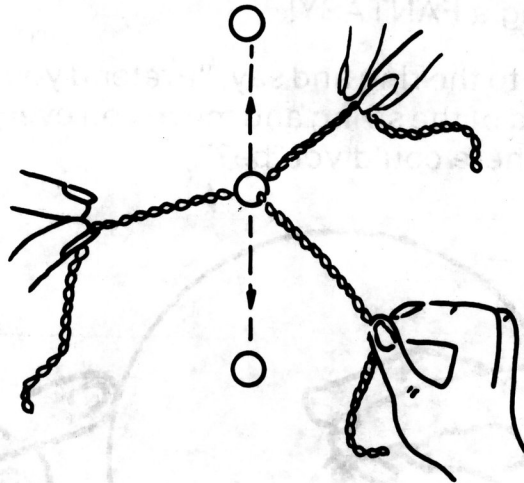
1. Attach one string to the ring and say, "Pretend you are tiny and sitting in this ring. If I hold the end of the string and move you everywhere I can, as far as the string will let me, where could you be?"



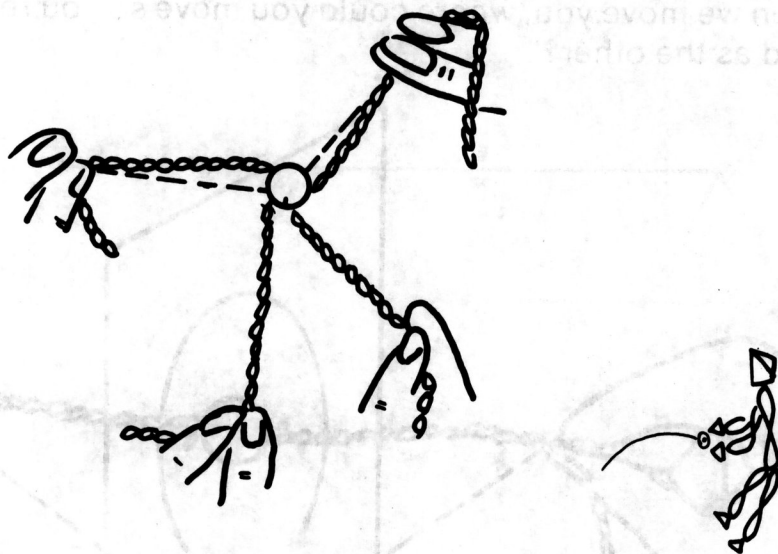
2. Attach another string and say, "Now I hold the end of each string in my hand. When we move you, where could you move so you remain just as far from one hand as the other?"



3. Attach another string and have someone help you hold one end of it, ask, "Where could you be if you are moved so you are always just as far from one of the hands as each of the others?"



4. Attach the fourth string and have another student help. Place your hands as pictured above, with one hand above the plane determined by the other three, and ask, "Where will you be? Can I move you?" (In the center point of the tetrahedron determined by the four hands. I can be only torqued or turned, but not moved out from that position.)



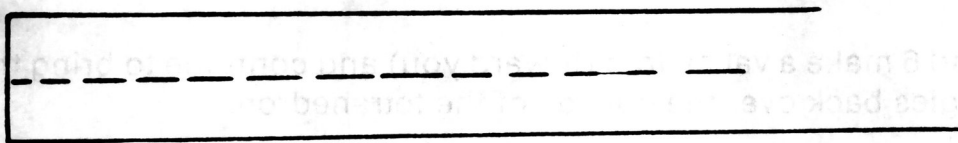
5. Explain, "These four points where we held our hands determine a SYSTEM. They divide space into six parts: the four points, the space inside the tetrahedron determined by those four points, and the space outside the tetra." Put your finger on each of the four points. Put your hand INSIDE the tetra and then put it OUTSIDE.

ACTIVITY 3

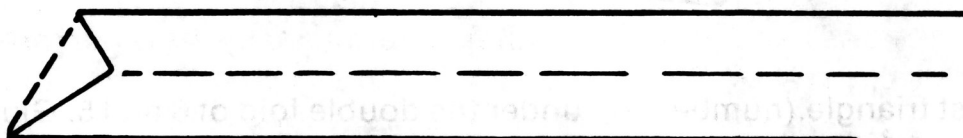
HOW TO FOLD A TETRAHEDRON FROM A STRIP OF PAPER?

Materials: Strips of paper for each student. (To make these fit patterns used later on, strips should be approximately 4.3 cm by 30 cm.)

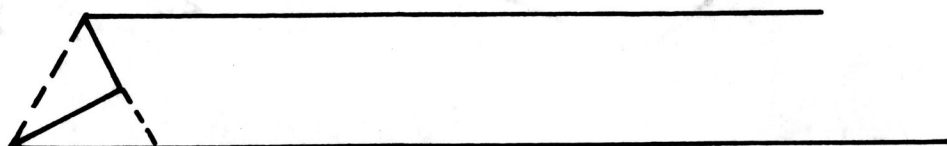
1. Fold a lengthwise crease half-way between the edges of the strip, extending just a short distance from one end.



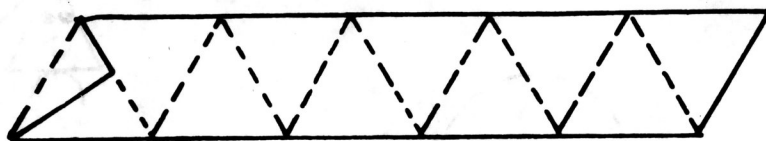
2. Fold a triangle from the end so the vertex of the right angle touches the middle crease line.



3. Fold away from you (mountain fold) to complete an equilateral triangle. Your first fold will exactly match the edge of the strip, and the right triangle will be on the outside.



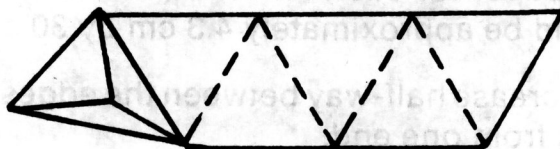
4. Fold over and over, each time a mountain fold so the bulk of the strip is on the outside. Each time make sure it exactly matches the edge of the paper.



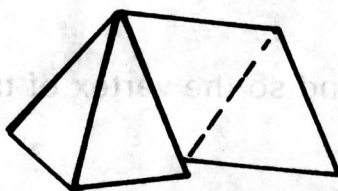
5. Undo the strip and number the triangles from one to ten; and cut off any left over.

"We have discovered a triangularly subdivided ribbon." Tetrascroll, 8

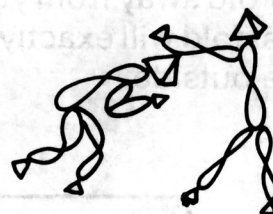
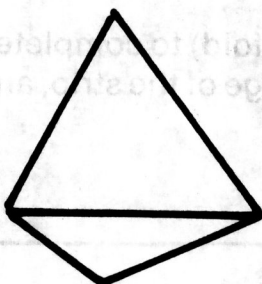
6. Fold between 1 and 2, 2 and 3, 3 and 4, 4 and 5, with mountain folds to form a tetrahedron.



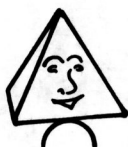
7. Between 5 and 6 make a valley fold (toward you) and continue to bring the remaining triangles back over the outside of the tetrahedron.



8. Tuck in the last triangle, (number 10), under the double fold of 6 and 5. Glue as you fold if you wish it to be permanent. It will stay together just by tucking in the last triangle.



9. Make several, or put your tetras together with you friends, and see if they will fill space.

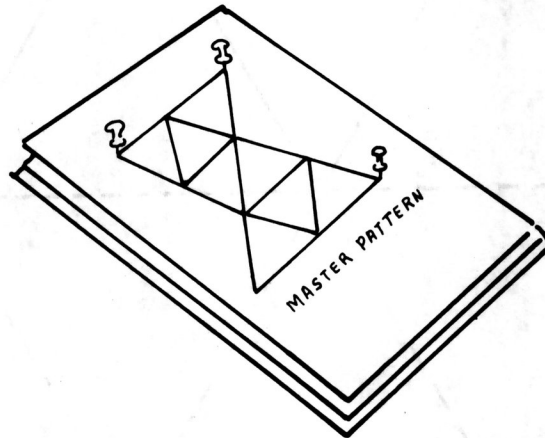


ACTIVITY 4

VOLUMES MEASURED WITH TETRAS AS UNITS

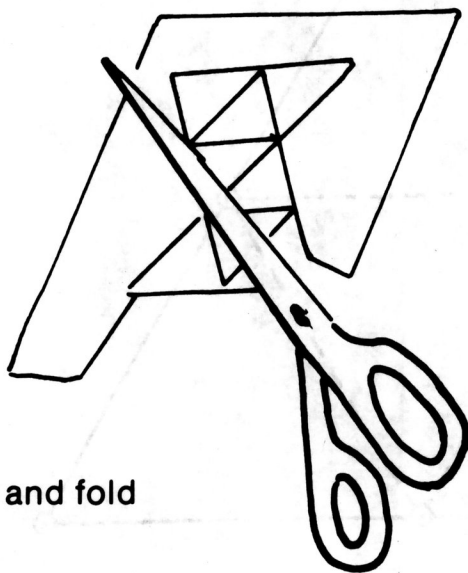
Materials: Patterns from the next pages; construction paper, scissors, glue, and push pins for making copies; birdseed for filling.

1. Place the pattern on top of a piece of construction paper with a magazine or cardboard underneath to protect the table. Pin through all points.

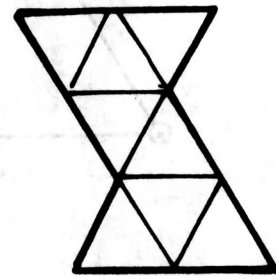


2. Draw and score lines to match the pattern.

3. Cut, fold, and glue to form the figure pictured.

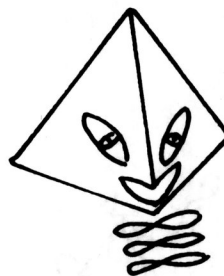


Cut and fold

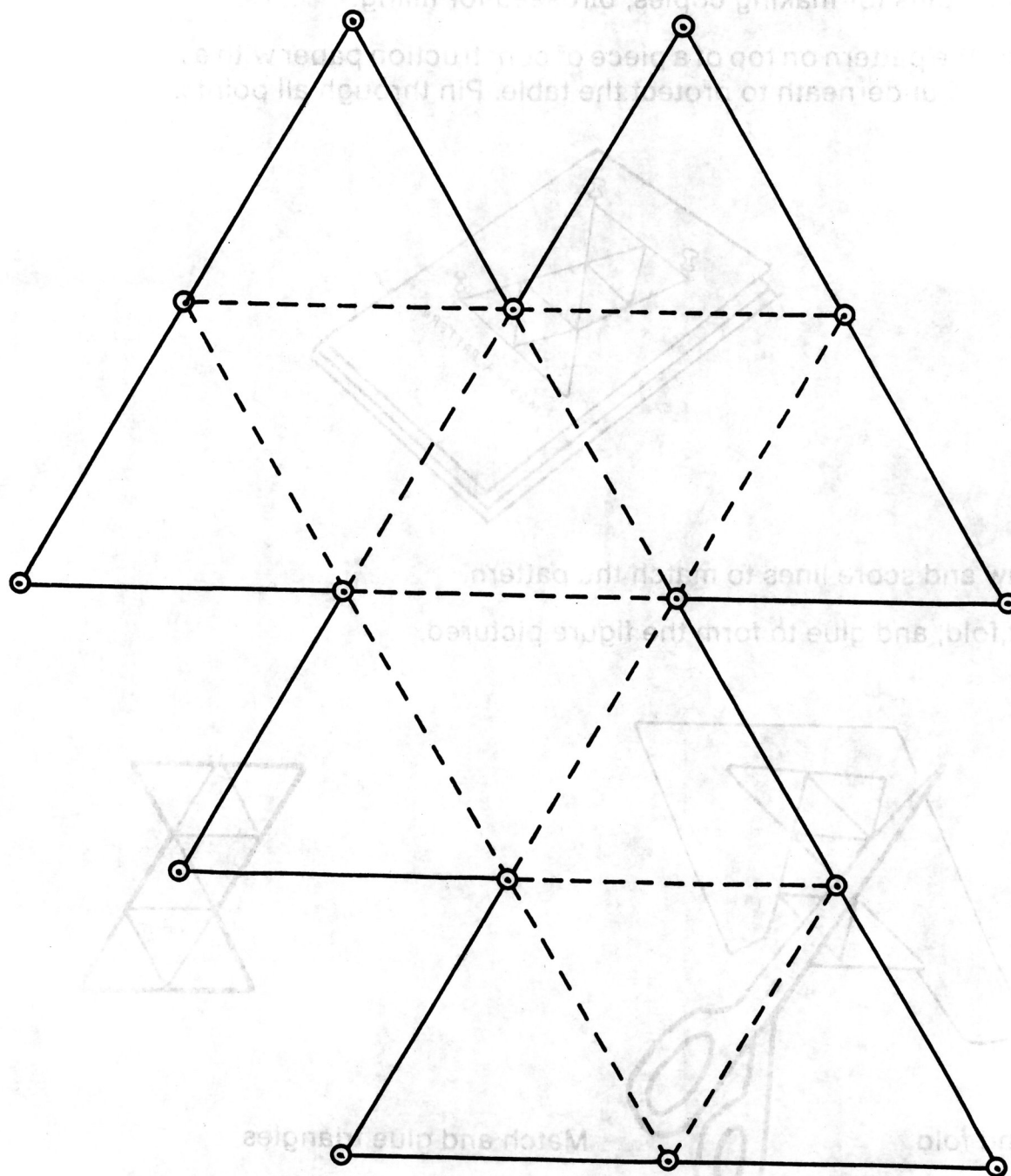


Match and glue triangles

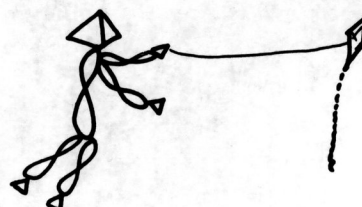
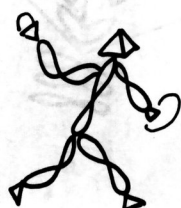
Directions from PUZZLES IN SPACE



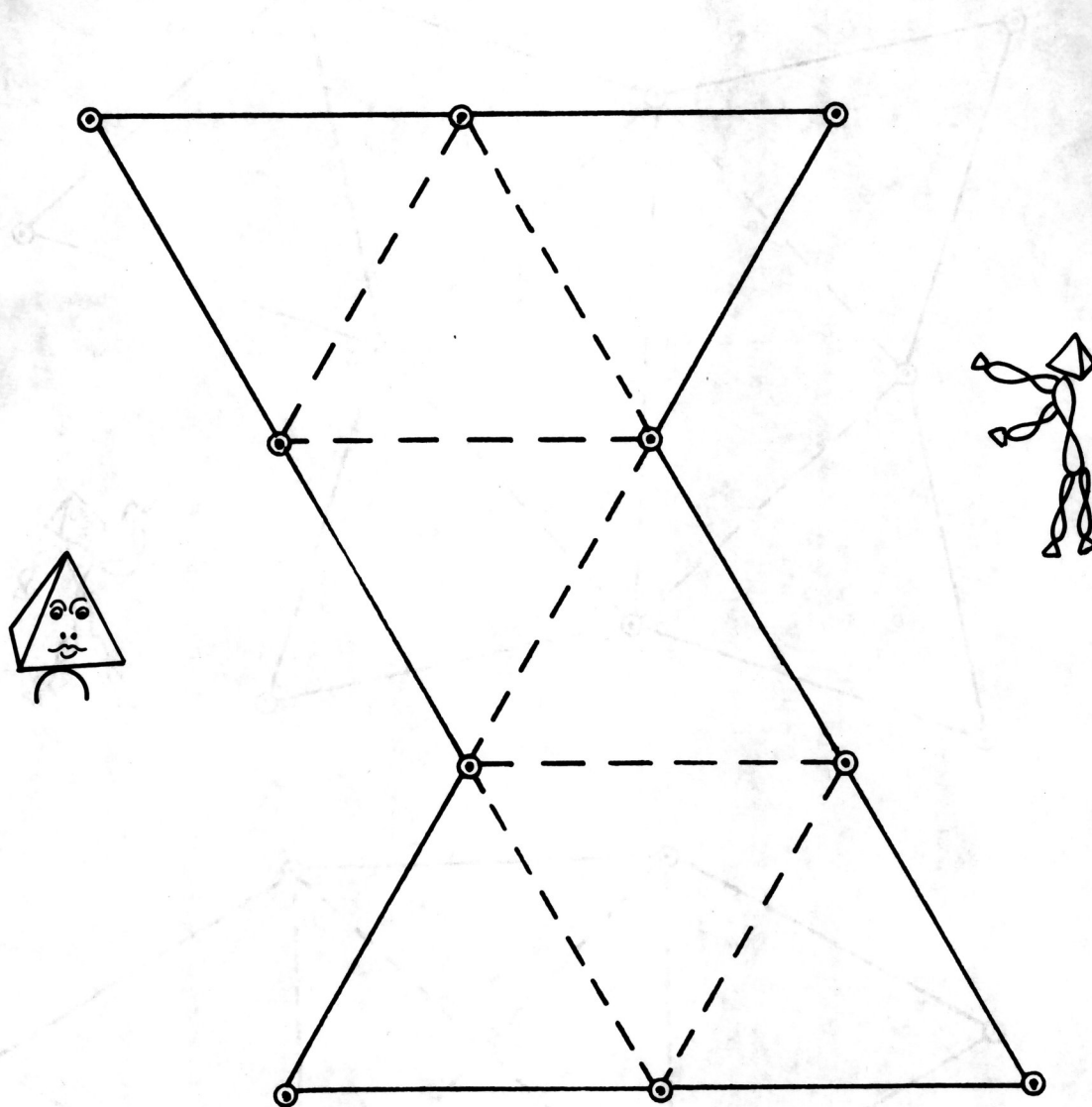
4. Make one each of the five figures A, B, C, D, and E with the patterns that follow.



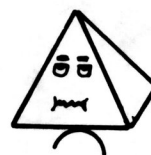
A. OCTAHEDRON
(8 faces)



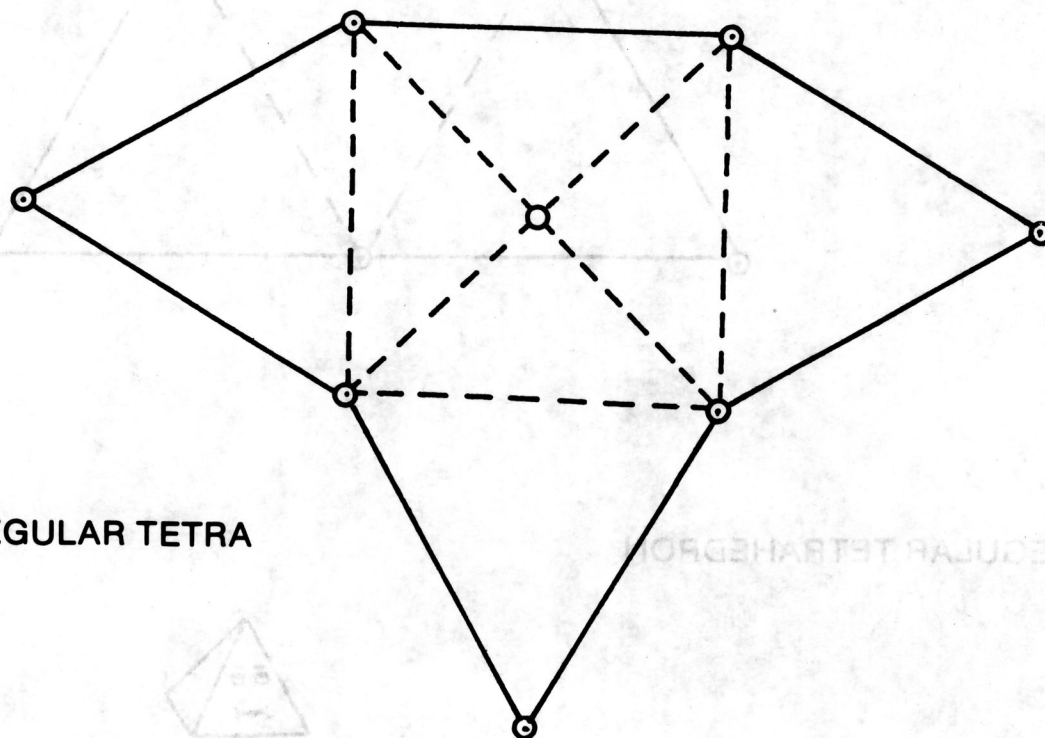
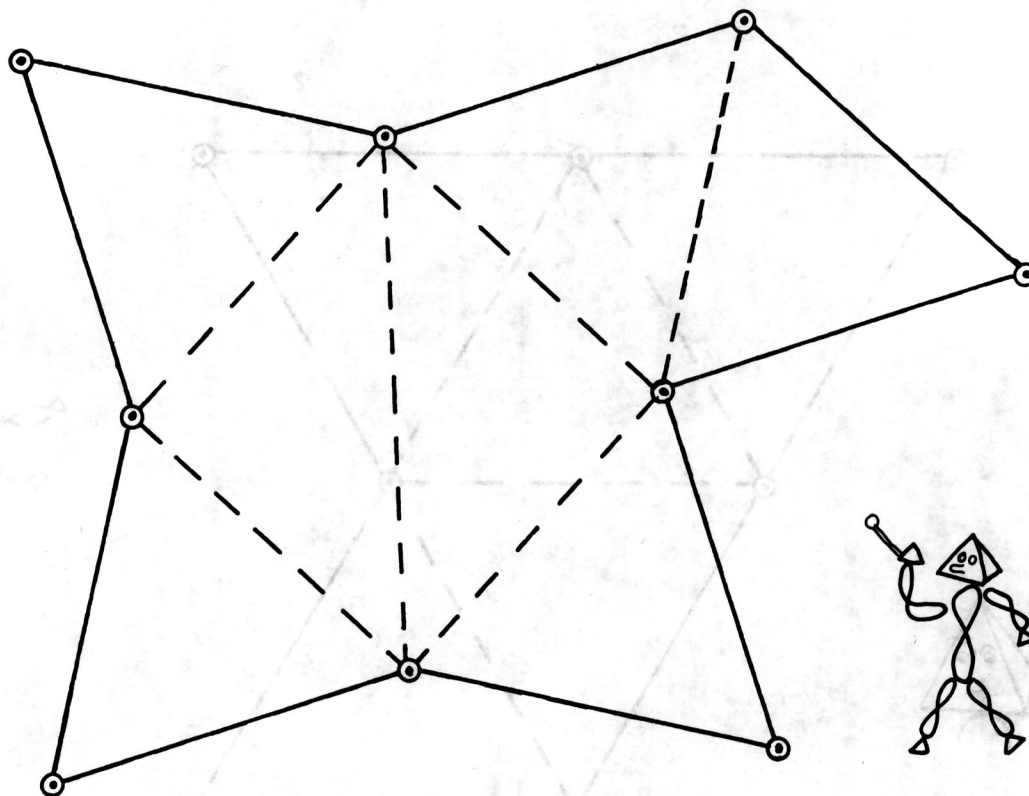
5. Since bases and heights of B and C are the same, their volumes are equal.
Test by making holes in the bases and filling with bird seed.



B REGULAR TETRAHEDRON

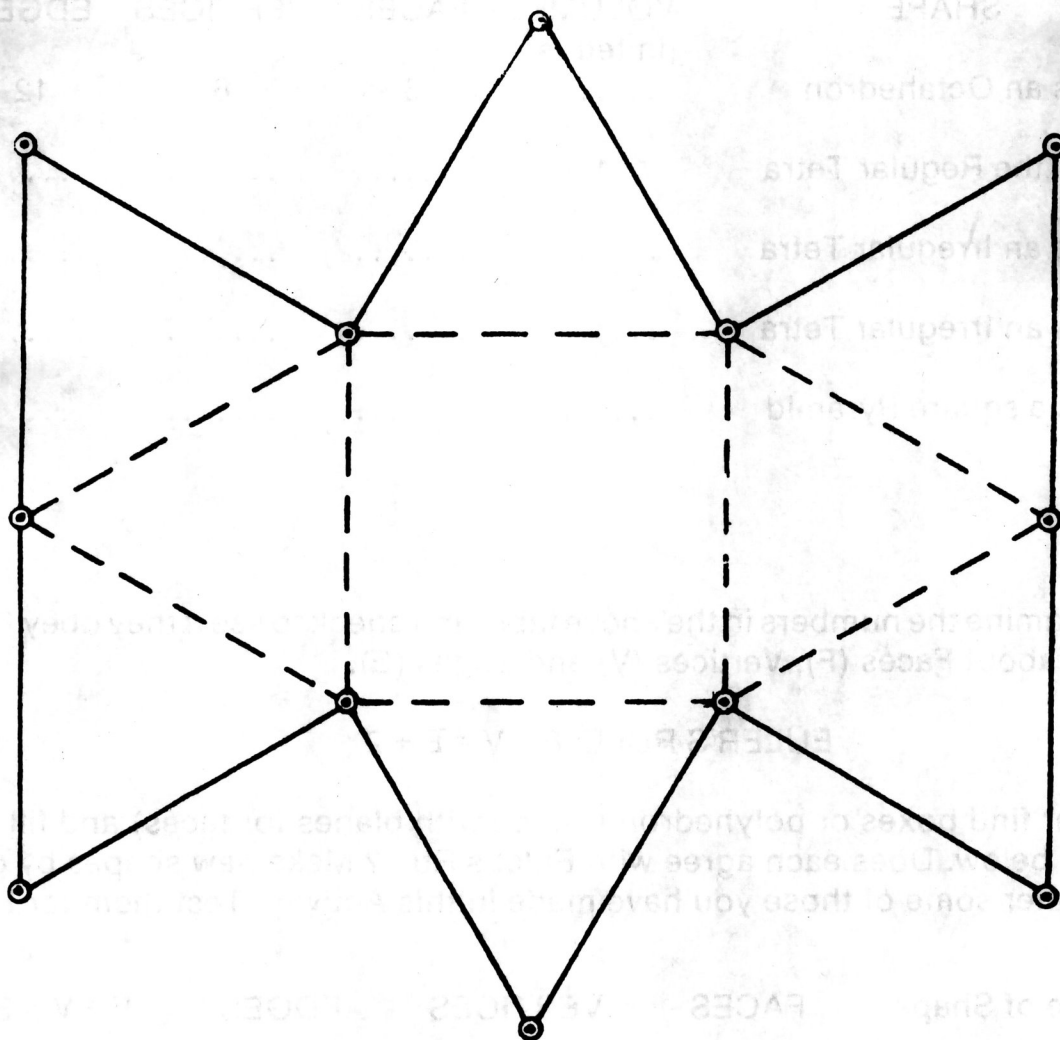


6. Make two of shape D and compare with C.
C. IRREGULAR TETRA

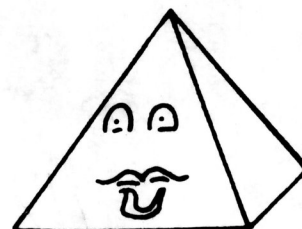


D. IRREGULAR TETRA

7. Make two of this square based pyramid. Compare them with A.



E. SQUARE BASED PYRAMID



8. Summarize your findings:

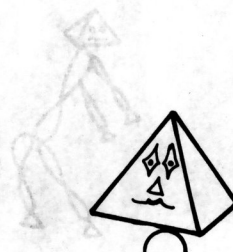
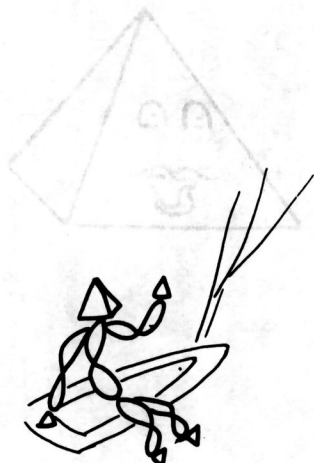
SHAPE	VOLUME (in tetras)	FACES	VERTICES	EDGES
A is an Octahedron		8	6	12
B is the Regular Tetra	1			
C is an Irregular Tetra				
D is an Irregular Tetra				
E is a square Pyramid				

9. Examine the numbers in the above table and check to see if they obey Euler's Rule about Faces (F), Vertices (V), and Edges (E).

$$\text{EULER'S RULE: } F + V = E + 2$$

Either find boxes or polyhedron (Solids with planes for faces) and fill in the table below. Does each agree with Euler's Rule? Make new shapes by gluing together some of those you have made in this Activity. Test them for Euler's Rule.

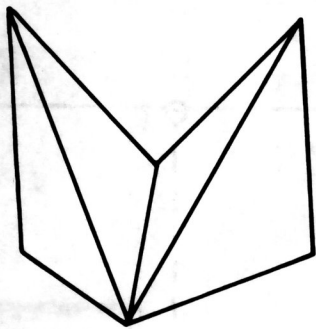
Name of Shape	FACES	VERTICES	EDGES	$F + V = E + 2 ?$
---------------	-------	----------	-------	-------------------



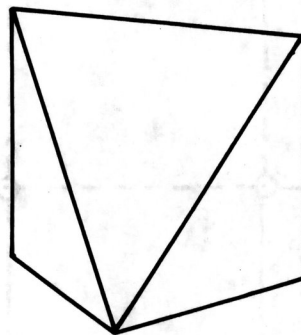
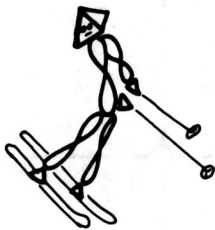
ACTIVITY 5 WHAT IS THE VOLUME OF A CUBE?

Materials: One tetra, pattern B; four tetras, pattern D.

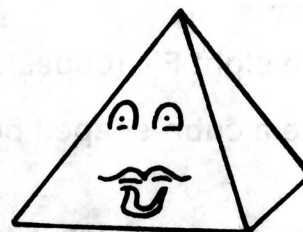
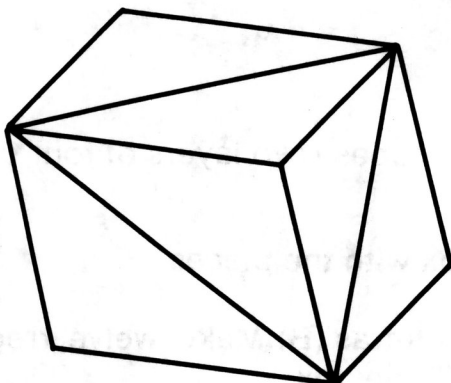
1. Place two D's with the equilateral triangles facing each other, edges aligned.



2. Set the regular tetra, B, so one edge touches the aligned edges.

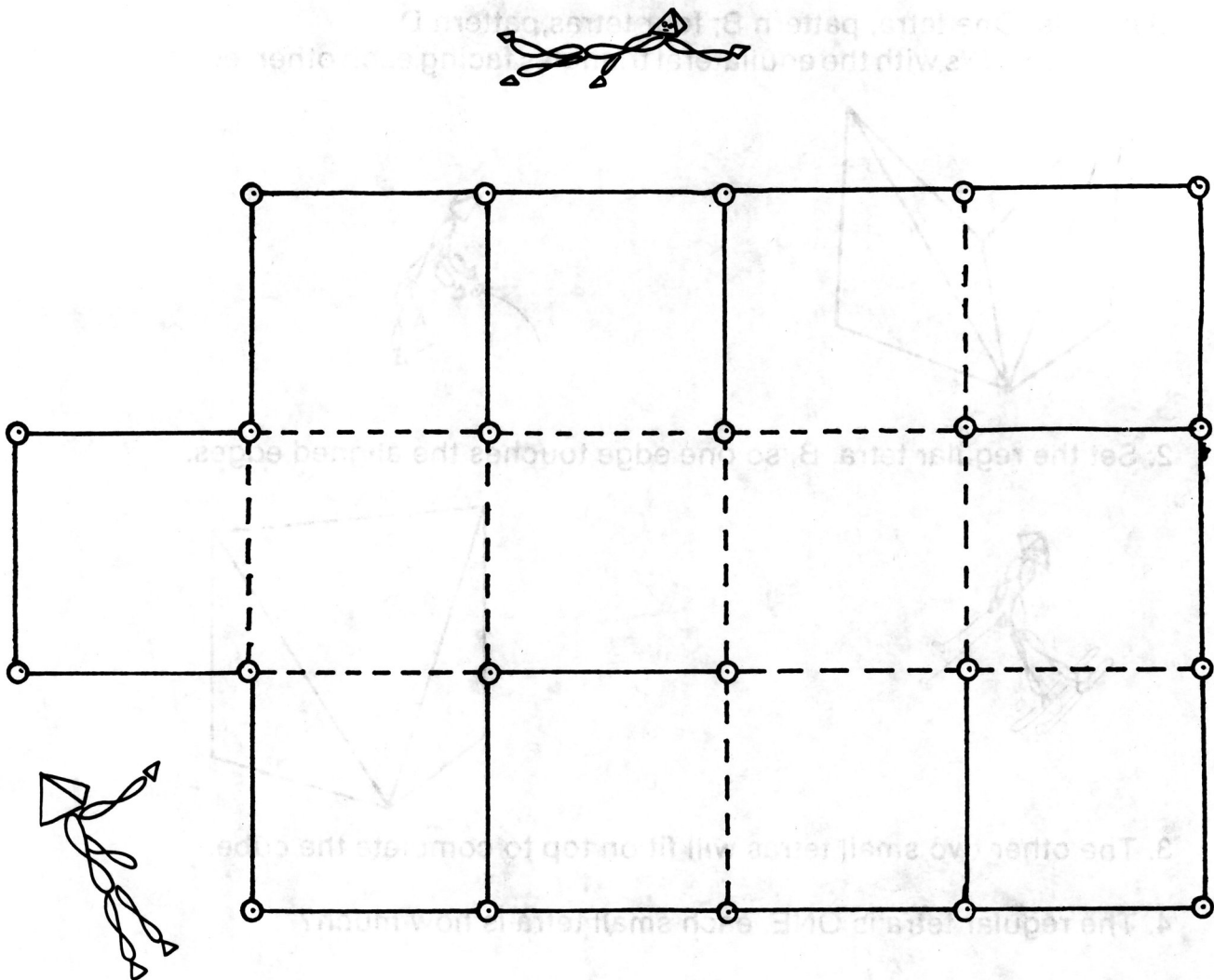


3. The other two small tetras will fit on top to complete the cube.
4. The regular tetra is ONE, each small tetra is how much?



5. What is the volume of the cube in tetra units?

6. Make a cube by this pattern. Compare it with the cube assembled from the five pieces on page 15.



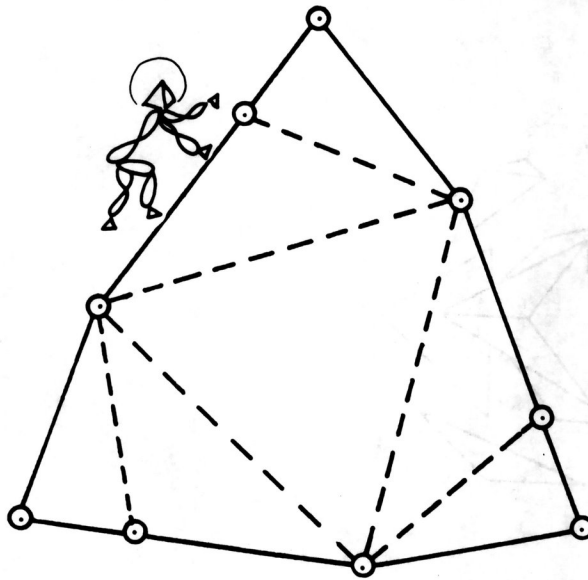
F. CUBE

1. Make eight F's (cubes).
2. Make a cube-shaped box to hold the eight cubes (two layers of four cubes each).
3. There are many ways to exactly fill this box with the pieces A-F. A few of them are:
 - a. Stellate an octa (A) with eight regular tetras (B). Make twelve irregular tetras (C). All of these together will fill the box.
 - b. Make six half octas (E) and eight regular tetras (B). Glue them together so no two of the same kind share a face. The resulting figure is a cuboctahedron. Using eight small irregular tetras (D) fill the box with the cuboctahedron in the middle.

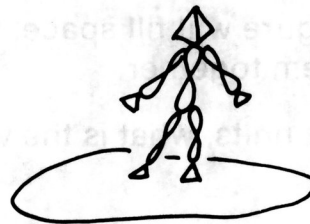
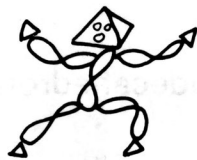
ACTIVITY 6

STELLATE AN OCTAHEDRON; WHAT DO YOU MAKE?

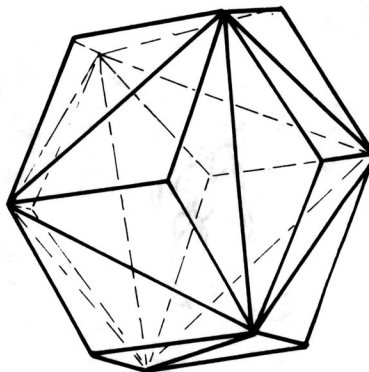
Materials: One octahedron from pattern C on page 10; eight shapes made from pattern G.



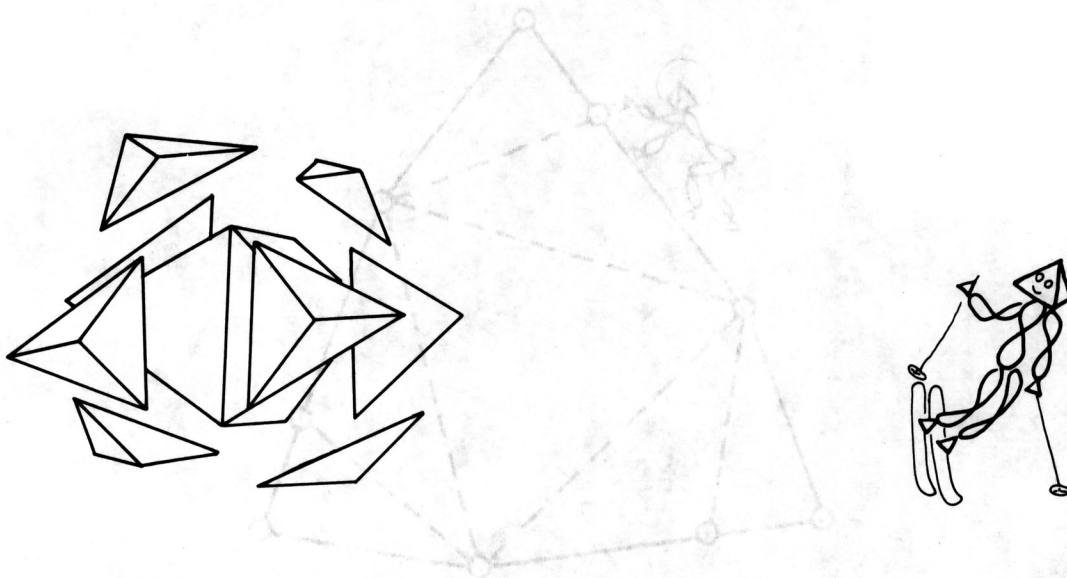
1. Assemble four of the G's to make a tetrahedron; what is the volume of each? Yes, each is one-fourth the tetrahedron, which is ONE.



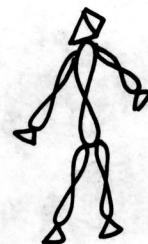
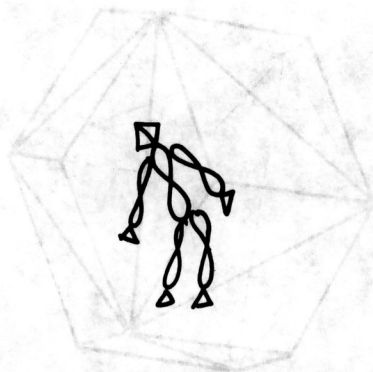
2. What is the volume of G in terms of the regular tetra, B?



3. Using all eight of the G's, put one on each face of the octahedron.
4. The solid made is a rhombic dodecahedron. The faces are rhombi (parallelograms with equal edges).



5. How many faces? (Dodeca- means 12)
6. This figure will fill space. If other students have made the same figure, try fitting them together.
7. In tetra units, what is the volume of the rhombic dodecahedron?

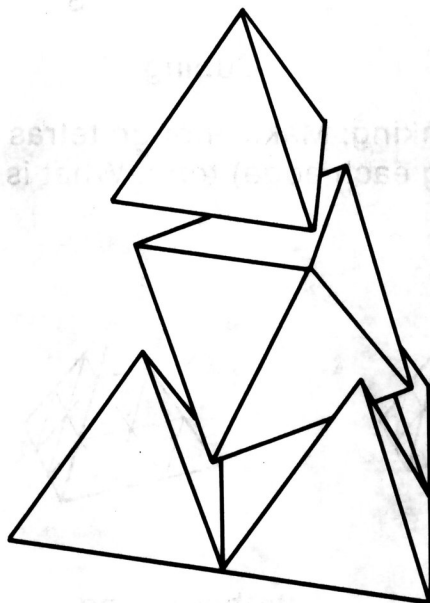


ACTIVITY 7

WHAT IS THE VOLUME OF A TWO-FREQUENCY TETRA?

Materials: Four regular tetras and one octahedron; Box of sugarcubes.

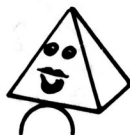
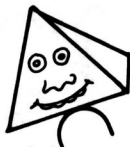
1. Assemble the five pieces to make a tetrahedron that is two units along each edge. Think of a unit as the length of the edge of the tetra.



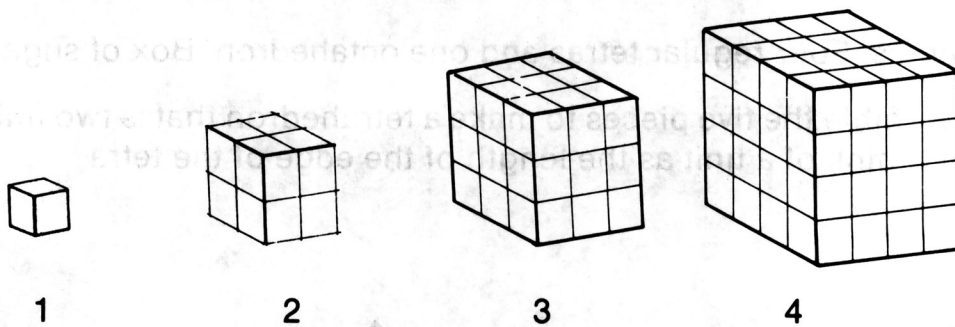
2. What Is the volume?

1 Octahedron
4 Tetrahedron
TOTAL

.....Tetras
4 Tetras
...Tetras

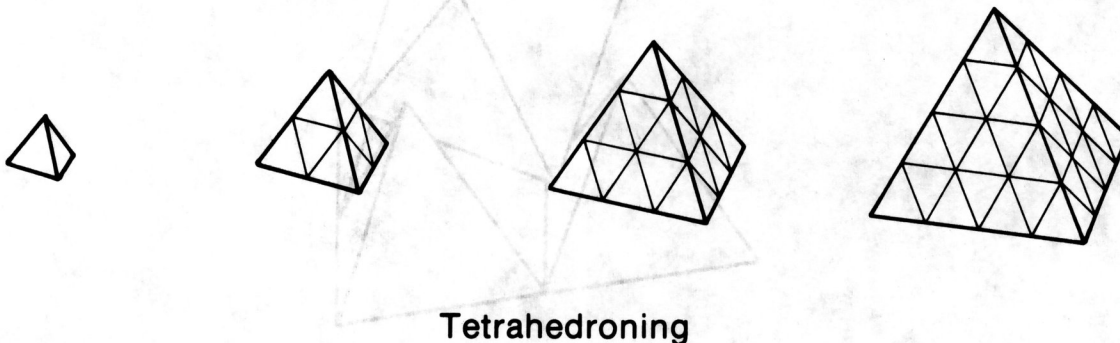


3. Using sugar cubes build the cubes of 1, 2, 3, and 4 frequency.



Cubing

4. More building and thinking: Make enough tetras and octas to build a three frequency (3 units along each edge) tetra. What is its volume? How about a four?



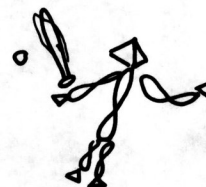
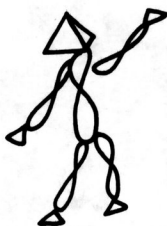
Tetrahedroning

5. What are the volumes?

One Frequency (1 tetra)
Two Frequency
Three Frequency
Four Frequency

Volume = 1
Volume = 8
Volume = 27
Volume = 64

6. What kind of numbers are the frequencies and volumes?

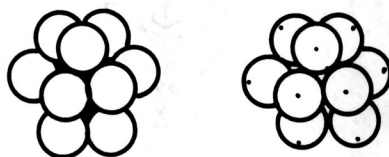


ACTIVITY 8

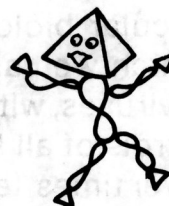
HOW MANY SPHERES PACK AROUND A CENTRAL SPHERE?

Materials: 13 small styrofoam spheres, 12 long pins, spool of dark thread.

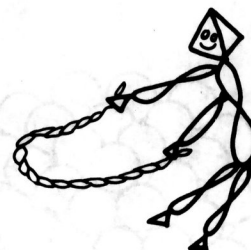
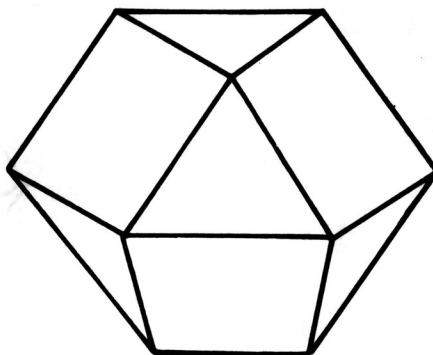
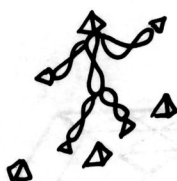
1. Place the long pins through the center (pole to pole) of twelve spheres.
2. Place them around the central sphere so each is tangent to the other.



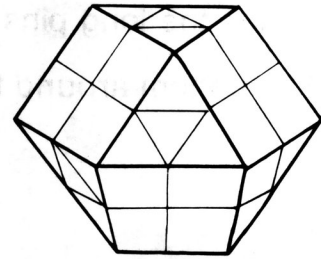
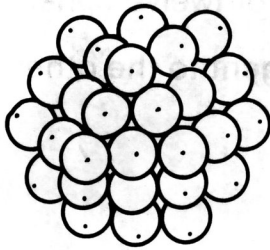
3. Thread around each pinhead so the six squares and 8 triangles are outlined.



4. Activity for experts: With more spheres and pins, add other layers. Connect the pin heads with the thread to show the pattern of 8 large triangles and six large squares.

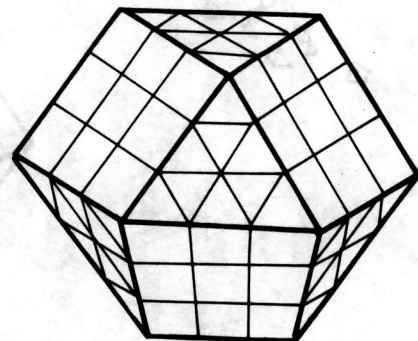
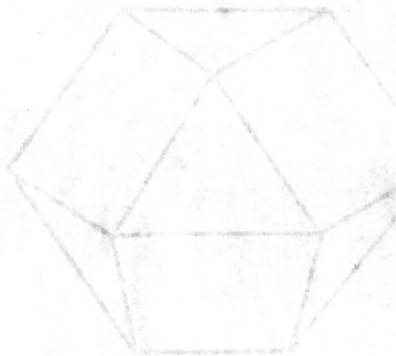
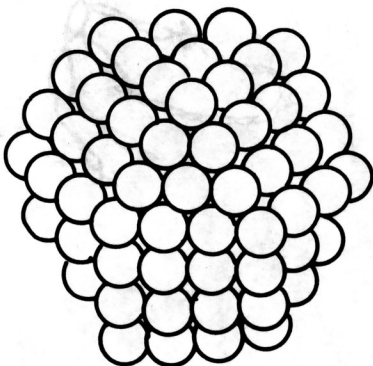
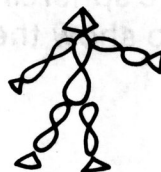


Higher Frequency of Packed Spheres (Optional for Experts)



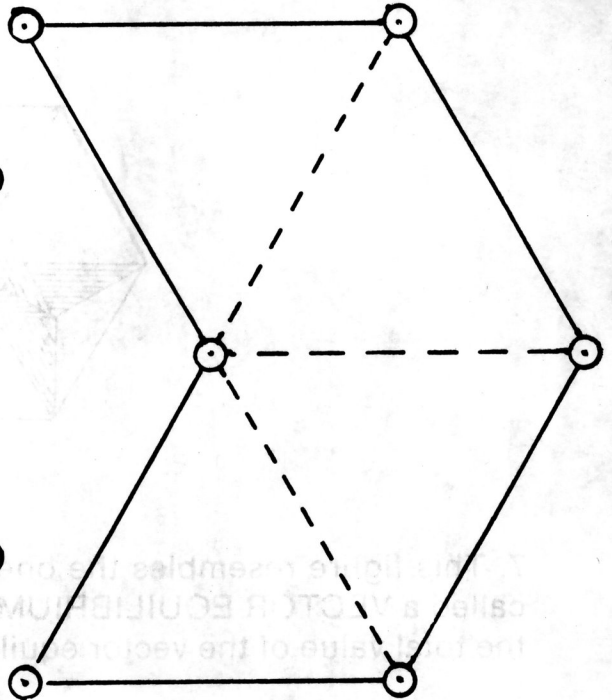
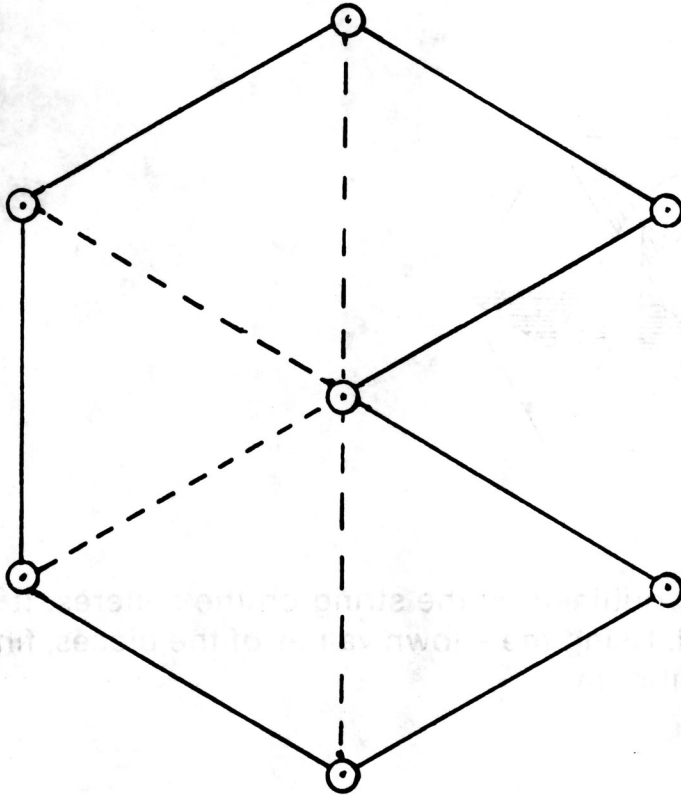
"The number of spheres (or vertices) on any concentric shell or layer is given by the equation $10F^2 + 2$, where F is Frequency. The frequency can be considered as the number of layers ...on the vector equilibrium. A one-frequency system has 12 spheres on the outer layer. If another layer of spheres are packed around the one-frequency system, exactly 42 additional spheres are required." SYNERGETICS, page 38.

" The molecular biologists have continued and developed my formulas by virtue of which we can predict the number of nodes in the external protein shells of all viruses, within which shells are housed the DNA-RNA programmed design controls of all biological species...all viruses employ frequency to the second power times ten plus two in producing the structural enclosures....It is the structural power of these geodesic-sphere shells that makes so lethal those viruses unfriendly to man. They are almost indestructible." SYNERGETICS, Page 36.



ACTIVITY 9 **WHAT IS THE VOLUME OF A VECTOR EQUILIBRIUM?**

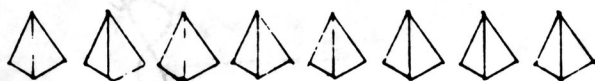
Materials: Six open base square pyramids, pattern below; eight open base tetras, pattern below.



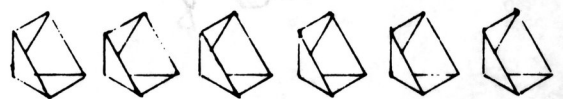
1. Make the fourteen figures.
 SQUARE PYRAMID (no base)

REGULAR TETRA (no base)

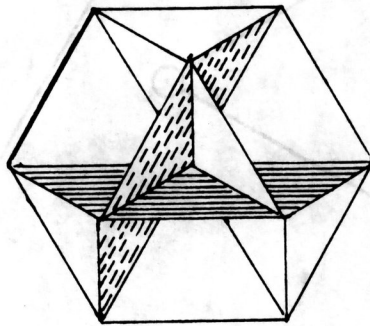
2. Fill the tetrahedron with birdseed. Fill the pyramid.



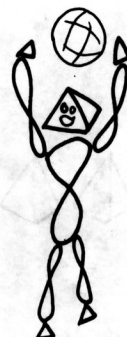
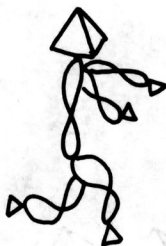
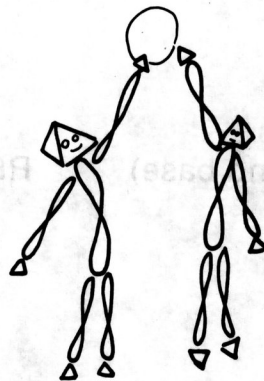
+



3. Glue a tetra on each triangular face of one square pyramid.
4. Glue four more square pyramids to the tetras on the figure.
5. Glue the remaining four tetras to the square pyramids.
6. Complete the figure by gluing on the last square pyramid.



7. This figure resembles the one outlined by the string on the spheres. It is called a VECTOR EQUILIBRIUM. Using the known values of the pieces, find the total value of the vector equilibrium.

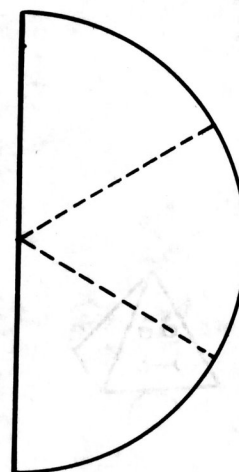
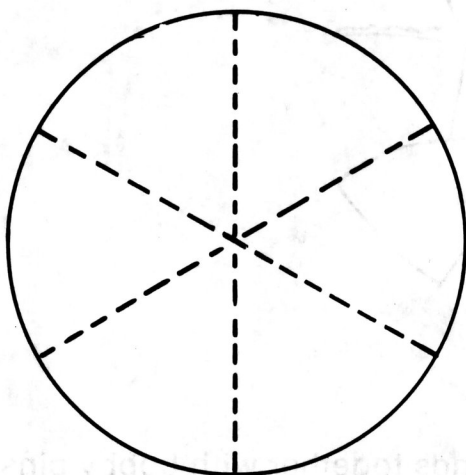


ACTIVITY 10

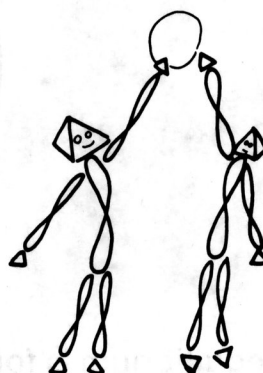
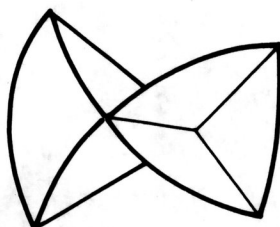
CAN "BOW TIES" MAKE A VECTOR EQUILIBRIUM?

Materials: Four circles of the same size; bobby pins, straight pins.

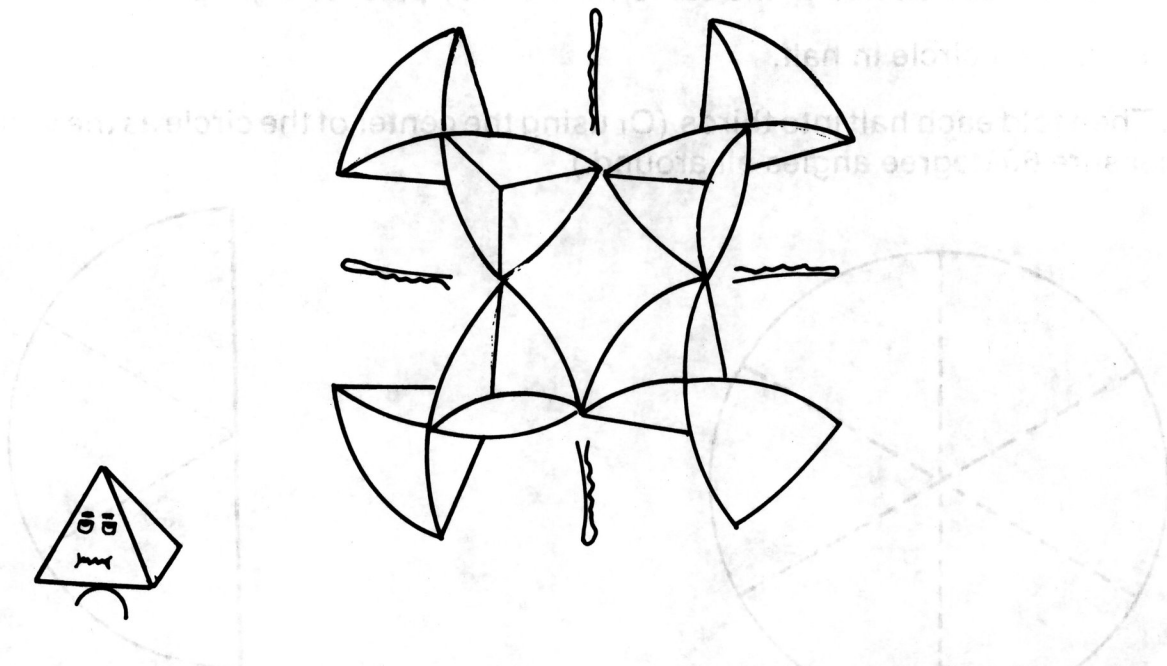
1. Fold each circle in half.
2. Then fold each half into thirds. (Or using the center of the circle as the vertex, measure 60 degree angles all around.)



3. From each circle, form a bow tie by fastening a pair of opposite radii together with a bobby pin.

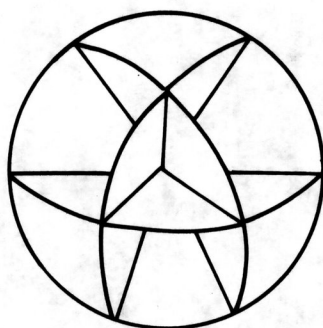


4. Arrange the four bow ties (so one end of each forms one side of a square), connect with bobby pins.



5. Hold the figure up and fasten the opposite ends together with bobby pins.

6. Did you feel a strong pull when you put in the last bobby pins? That is synergy in action!



"The vector equilibrium is formed by four great circles folded into "bow ties." The sum of the areas of the four great circles equals the surface area of the sphere, $4 \pi \text{ radius squared}$."

SYNERGETICS, page 468

7. With colored pens, outline the great circles. How many?

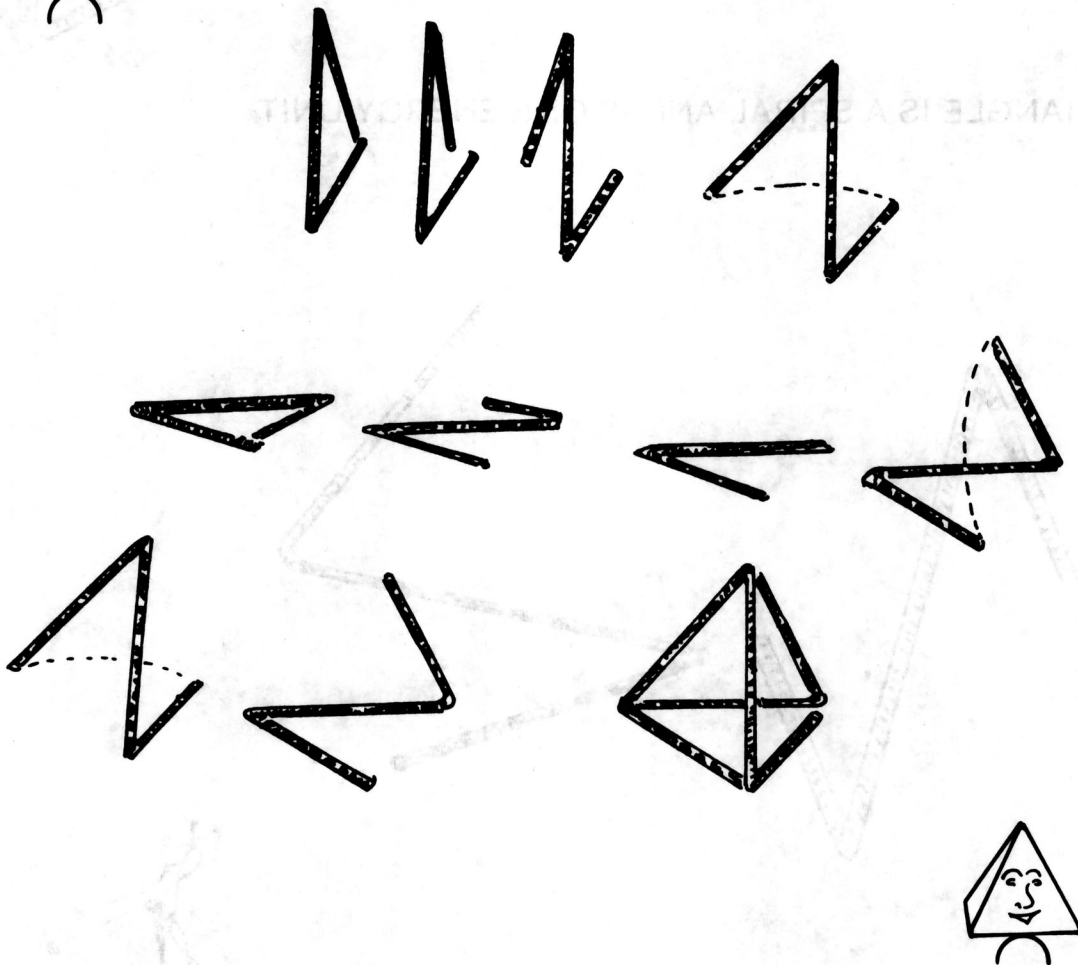
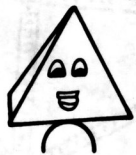


ACTIVITY 11

1 AND 1 = 4 ? WHEN?

Materials: Two pipe cleaners.

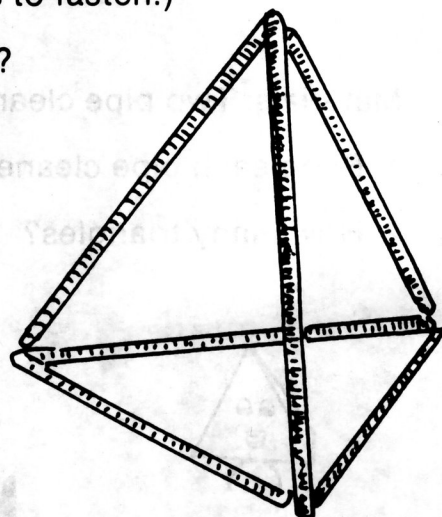
1. Bend each pipe cleaner to form an equilateral triangle.
2. How many triangles?



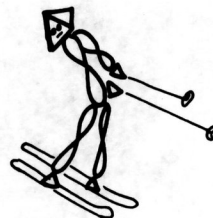
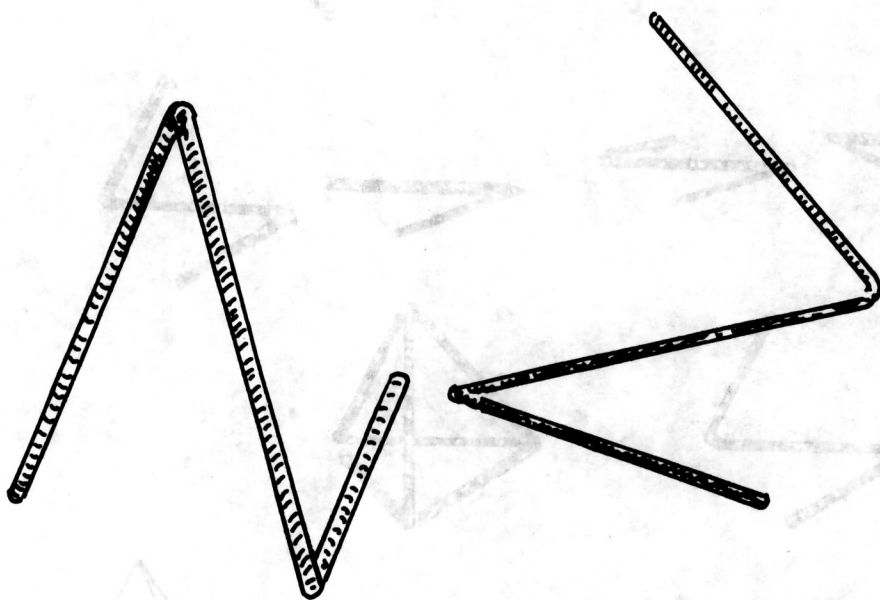
3. Pull the left third of one triangle up until it makes about a sixty degree angle with the plane of the other two.
4. Pull the right third of the other triangle until it makes about a sixty degree angle with the plane of the other two.

5. Assemble the two as pictured below.. (Bend ends to fasten.)

6. How many triangles on this tetrahedron skeleton?



A TRIANGLE IS A SPIRAL AND IS ONE ENERGY UNIT

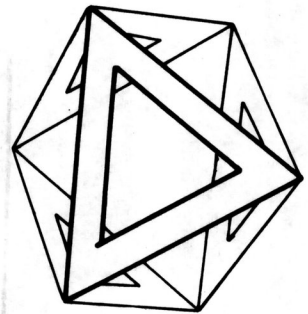
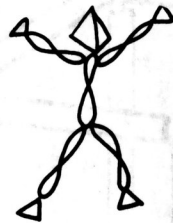
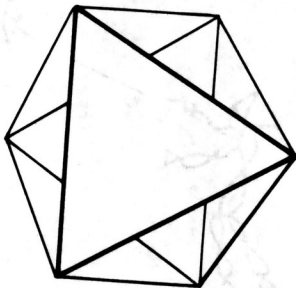


ONE POSITIVE + ONE NEGATIVE EVENT
=TETRAHEDRON

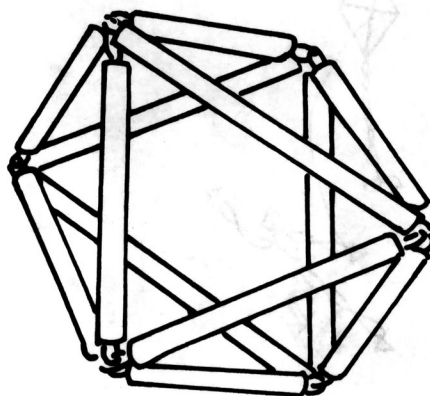
ACTIVITY 12
DOES 2 AND 2 = 8 ? WHEN ?

Materials: Four soft cardboard equilateral triangles; 8 Straight pins; 12 straws the same length; 24 hairpins that fit snugly into the ends of the straws.

1. Fasten the vertices of the four triangles together, pair by pair, so no edges touch. Pins will hold it.
2. How many triangles are outlined (4 solid and 4 empty)?



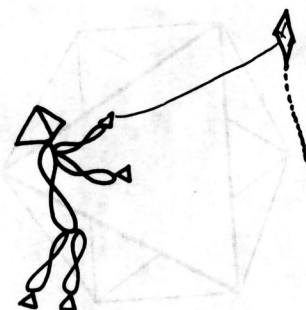
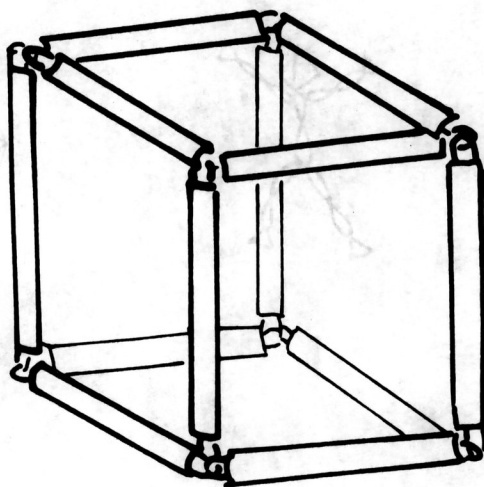
3. Remove the pins and cut a triangle from the middle of each. Reassemble with the pins.
4. Does this better resemble an octahedron?
5. Using hairpins and straws, assemble the octahedron as pictured.



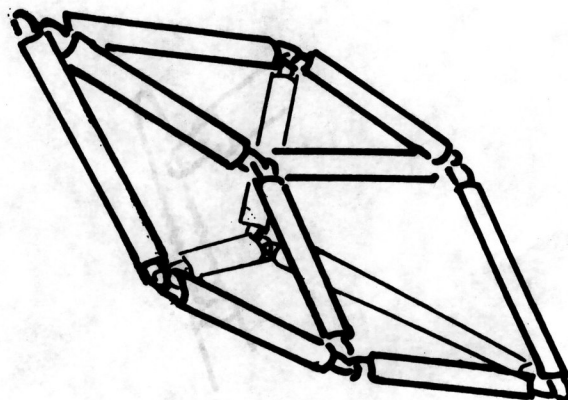
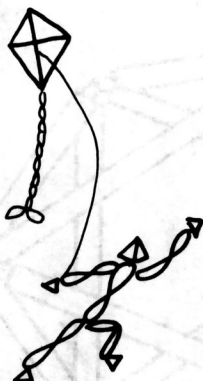
ACTIVITY 13 IS A STRAW CUBE RIGID?

Materials: Twelve five-centimeter straws of one color; twelve seven-centimeter straws of two different colors, if possible; 24 hairpins.

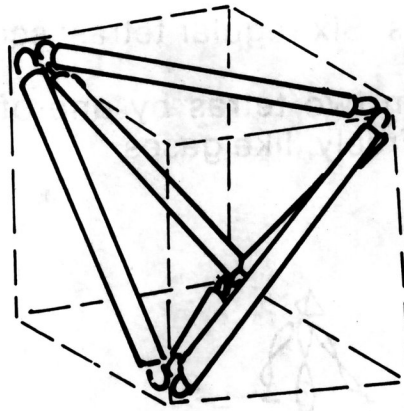
1. Assemble the cube with straws and hairpins as pictured.



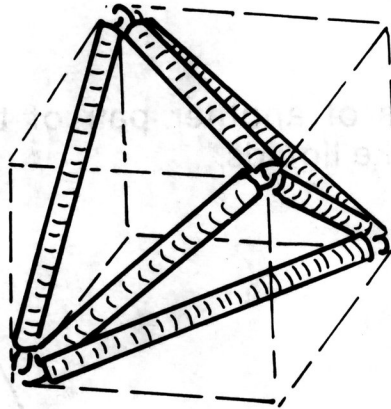
2. Does it collapse? Yes, it is NOT rigid !!



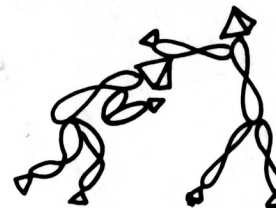
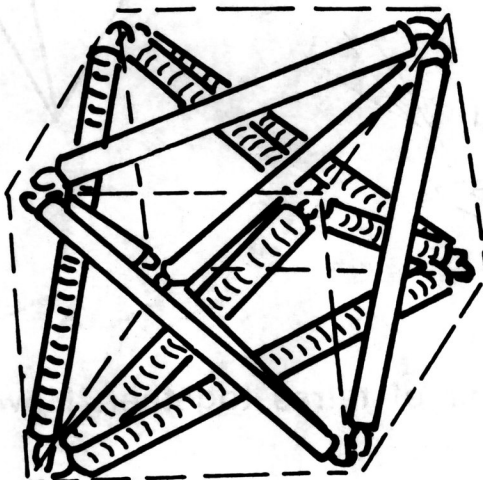
3. Place the 7 centimeter straws as diagonals of the faces of the cube, to form a tetrahedron.



4. Using six straws of another color, make another tetra in the cube by connecting the other opposite vertices.



5. This is an unusually rigid model. Again, it illustrates synergy...the forces of objects working together is greater than the separate parts. This is a model for alloys, which are stronger than pure metal.

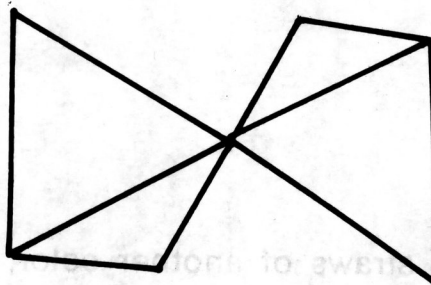
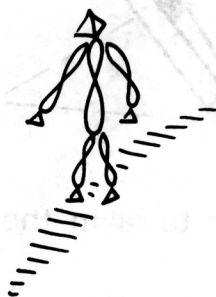


ACTIVITY 14

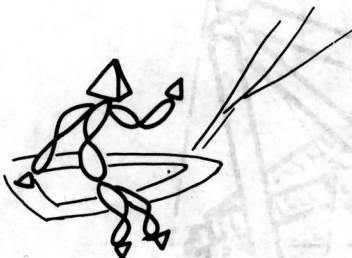
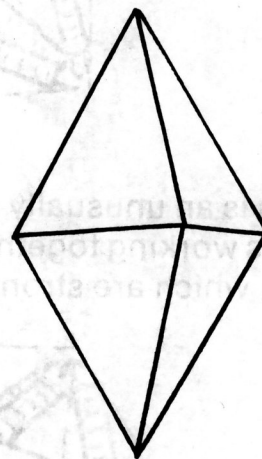
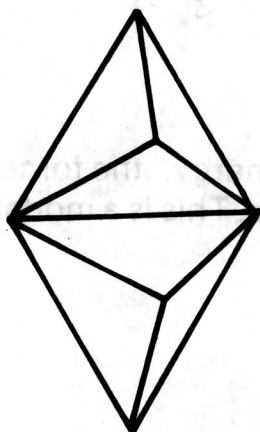
HOW DO GASES, SOLIDS, AND LIQUIDS MOVE?

Materials: Six regular tetras; scotch tape; glue; a pin.

1. Fasten two tetras by one of their vertices with a pin. How does it move? Freely, like gases.

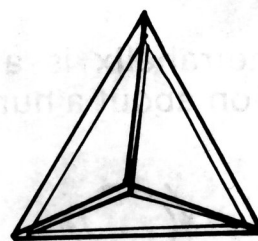
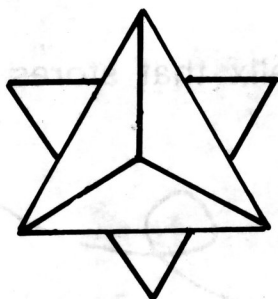


2. Use tape to fasten the edges of another pair of tetras together. How do they move? On a hinge, like liquids.

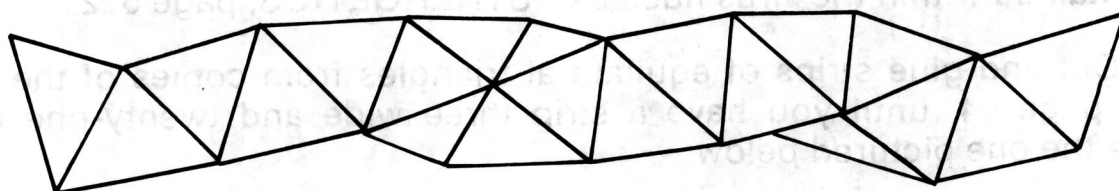


3. Glue two faces of the last pair of tetras together. How do they move? Not at all, like solids.

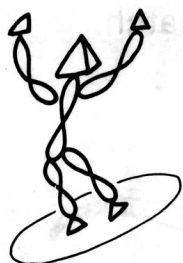
4. "The quadri-bond and mid-edge coordinate tetrahedra system demonstrates the super strength of substances such as diamond and metals." Synergetics, 518



5. The tetrahelix is a helical array of triple-bonded tetrahedra. Make 20 of the tetras using pattern B on page 11. Glue them together in pairs first, then glue the pairs to make the arrangement pictured below.



6. Mark each edge with a different colored marking pen. These curves are helical paths. Each curve is a helical path of almost 360 degrees, or almost a complete turn.

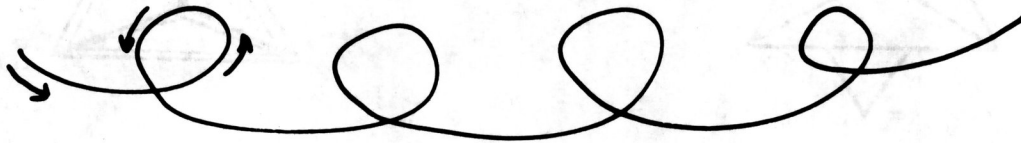


ACTIVITY 15

WHAT HAPPENS WHEN YOU "UNZIP" THE TETRAHELIX?

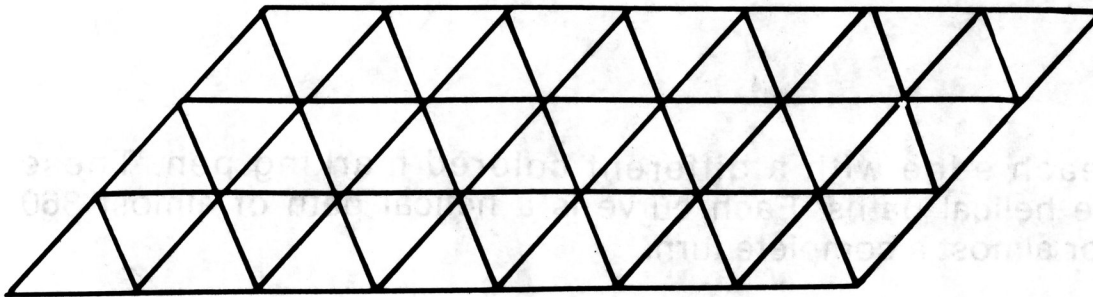
Materials: The tetrahelix made in Activity 14, Triangular Grid paper from page 64.

1. This tetrahelix is a model of the DNA Helix that stores all the information about a human being.



"These helical columns of the tetrahedra, which we call a tetrahelix, explain the structuring of DNA models of the control of the fundamental patterning of nature's biological structuring as contained within the virus nucleus." SYNERGETICS, page 522.

2. Cut and glue strips of equilateral triangles from copies of the grid on page 64, until you have a strip three wide and twenty-one long like the one pictured below.



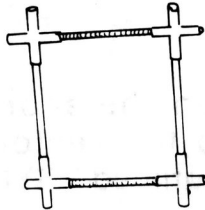
3. Wrap this strip around your tetrahelix. Does it fit?
4. Remove it and tape the edges so the lines of the grid match.
5. The back of a snake resembles a tetrahelix.



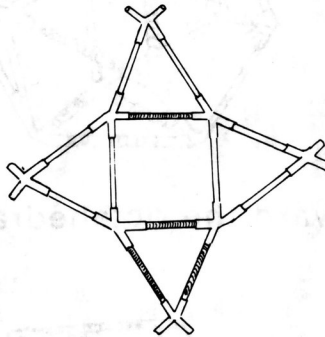
ACTIVITY 16 WHAT IS A JITTERBUG ?

Materials: Twenty-four dowels about 10 centimeters long; 48 pieces of surgical tubing that fits snugly over the dowel (each piece about 5 centimeters long).

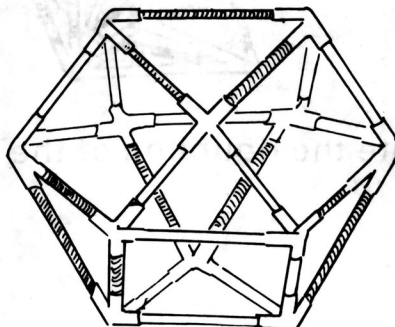
1. First, slit 24 pieces of tubing in the middle, just enough to pull an unslit piece through to make a cross.
2. Using four dowels and four of the cross pieces assemble a square.



3. On each side of the square use two more dowels and a tubing cross to form triangles.

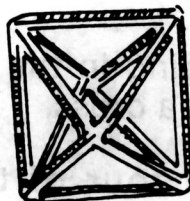


4. Use two more dowels and a cross to make squares between the triangles.

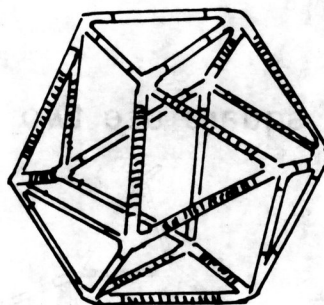


5. With the last four dowels form the square opposite to the one you started with. This is Bucky's Jitterbug ! See what it will do on the following pages!

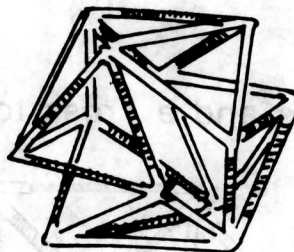
6. Stand the jitterbug on one of the triangles and place your hand on the opposite triangle. By pressing, you will collapse the figure into a double rod octahedron.



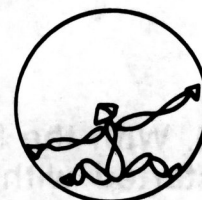
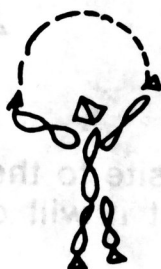
'The icosahedral phase: When the short diagonal dimension of the quadrilateral face is equal to the vector equilibrium edge length, 20 equilateral triangular faces are outlined.'" SYNERGETICS, page 194



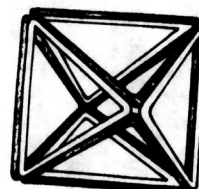
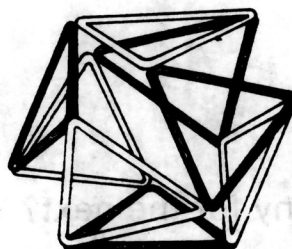
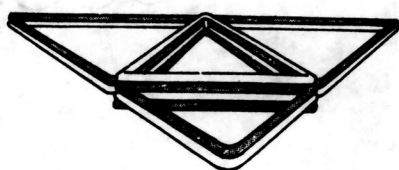
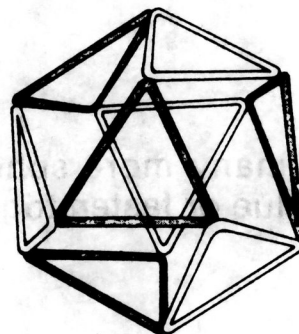
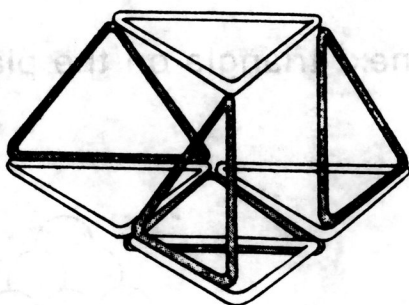
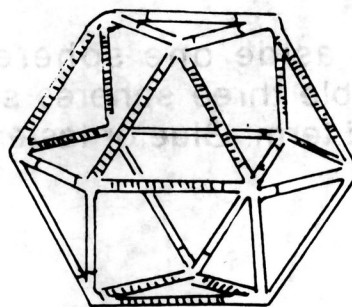
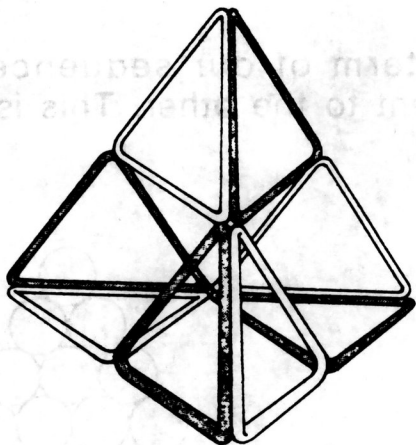
"Further contraction toward the octahedral phase." SYNERGETICS, page 194



Octahedral phases: Note the doubling of the edges." SYNERGETICS, page 194.



7. Look at each solid you make and count the faces, the vertices, and the edges. There is an important relationship.

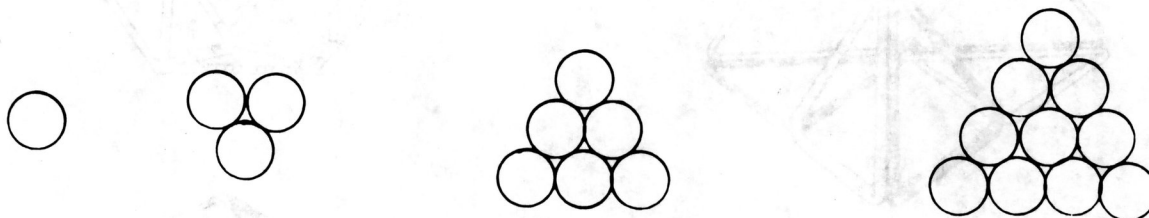


ACTIVITY 17

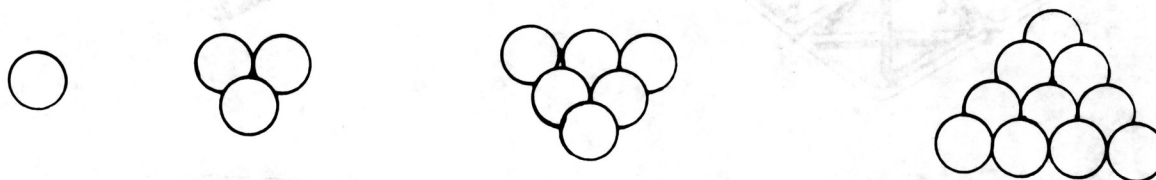
HOW CAN SPHERES FORM A TETRA?

Materials: Twenty styrofoam spheres or marbles; pins for styrofoam or glass cement for marbles.

1. Set aside one sphere for the first term of our sequence. 2. Assemble three spheres so each is tangent to the other. This is the second term. Glue or fasten together.

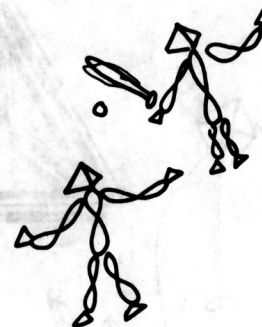
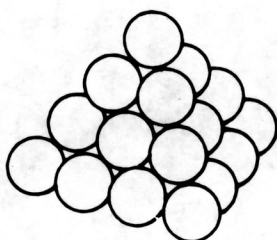


3. How many more spheres to make the next triangle on the plane? Yes 6. Glue or fasten together.



4. How many for the next? Yes 10. Glue or fasten together.

5. Using these as layers make a tetrahedron.

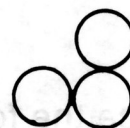
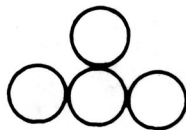


ACTIVITY 18

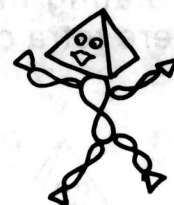
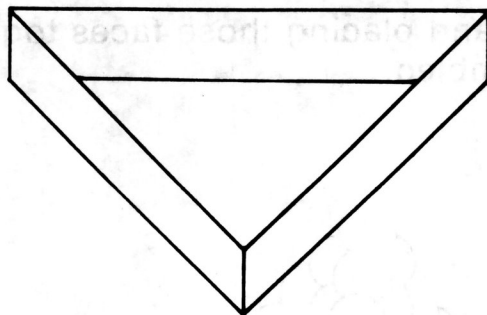
CAN YOU SOLVE THE TETRA PUZZLE ?

Materials: 20 spheres, glue for marbles, pins for styrofoam.

1. This time fasten the spheres like the diagrams.
2. Now, assemble the same tetra on page 32.



Make a triangular "fence" to set the pieces in.



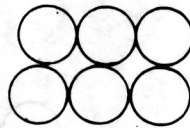
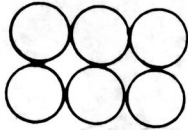
THIS IS A HARD PUZZLE !

ACTIVITY 19

THE TETRAHEDRA IN TWO PIECES:BUCKY'S FAVORITE !

Materials: 20 spheres of styrofoam with pins or marbles with glass cement.

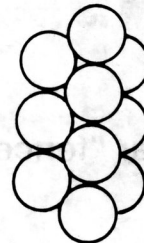
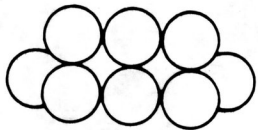
1. Arrange and fasten two 2 by 3 rows of spheres.



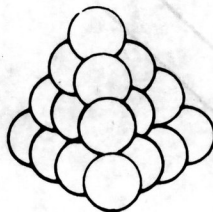
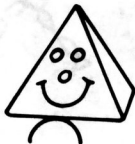
2. Fasten two rows of four each.



3. Place the four on top of the 2 by 3 so the spheres are tangent.



4. By rotating the 2 by 3 's and placing those faces together the same 20 sphere tetra can be assembled.



ACTIVITY 20

WHAT ARE HEXAGONAL NUMBERS ?

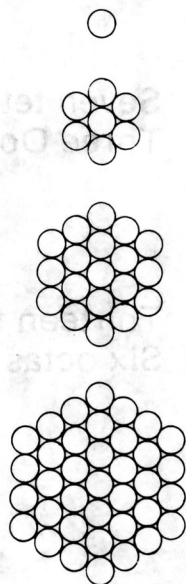
Materials: Circles or discs..at least 64.

1. Using tangent circles use one circle for the first term; for the second take another circle and surround it with tangent circles.

How many? Yes 7, $1 + 6 = 7$.

3. For the third term start with 7 , surround with tangent circles. How many?

4. Continue for a fourth term. What is the sequence?



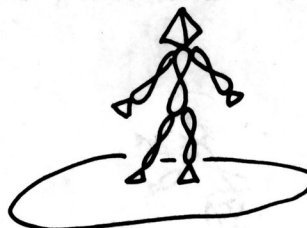
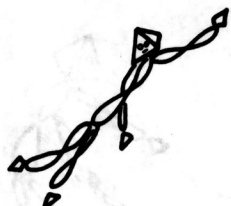
First 1

Second $7 = 1 + 6$

Third $19 = 1 + 6 + 12$

Fourth $37 = 1 + 6 + 12 + 18$

Could you guess the fifth? Check by building.



ACTIVITY 21 TETRAHEDRAL FREQUENCY AND HEX NUMBERS

Materials: Octahedron and tetrahedron.

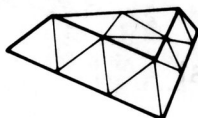
Build the four layers of the four frequency tetra.



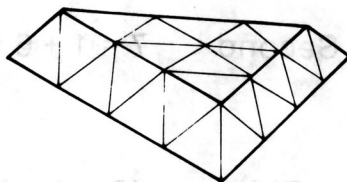
One tetra = 1



Three tetra = 3
One Octa = 4



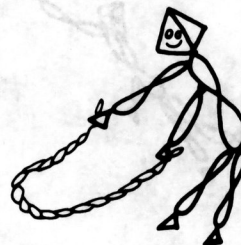
Seven tetra = 7
Three Octas = 12



Thirteen tetras = 13
Six octas = 24

1. Stack the first two layers? What volume?
2. Stack the first three layers? What volume?
3. Stack the first four layers? What volume?
4. Extension: IF you had a fifth layer, what do you THINK the volume of the entire tetra would be?

How many tetras and how many octas? Build to check it!!

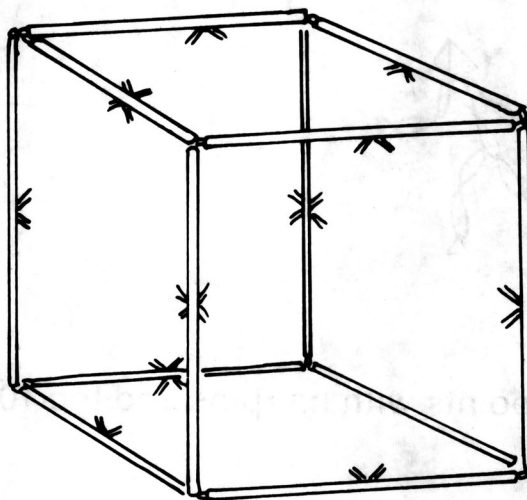


ACTIVITY 22

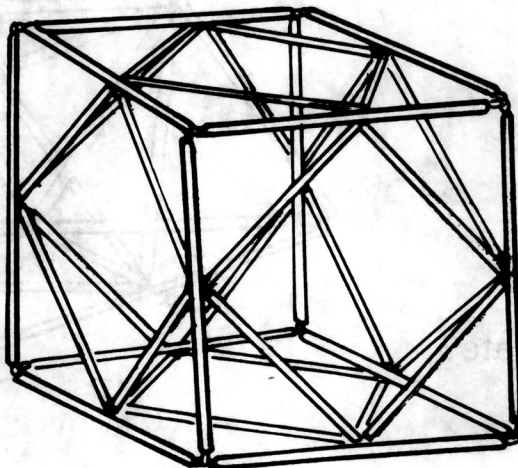
HOW DOES A CUBE RELATE TO A VECTOR EQUILIBRIUM ?

Materials: Twelve 20 cm straws; twelve 14 cm straws (A different color, if possible); hairpins.

1. Assemble a cube with hairpins and the 12 30 cm straws.



2. Using the 12 14 cm straws and hairpins , connect the midpoints of the sides...



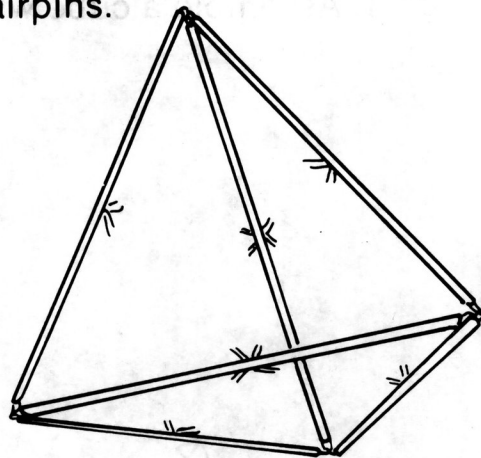
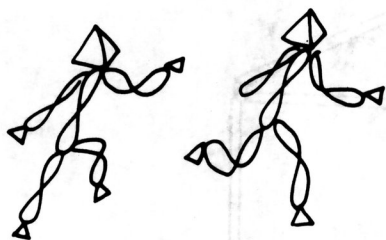
3. That's why a vector equilibrium is called a cuboctahedron!

ACTIVITY 23

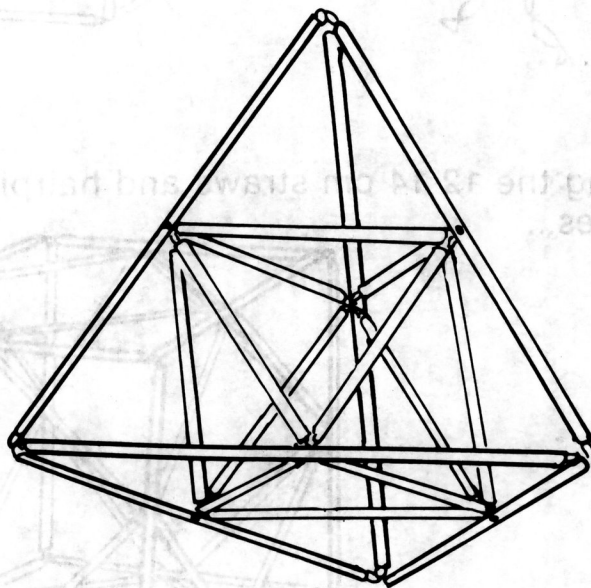
HOW DOES A TETRA RELATE TO AN OCTAHEDRON ?

Materials: Four 20 cm straws; twelve 10 cm straws (another color if possible); hairpins.

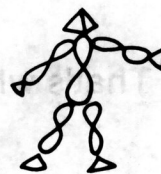
1. Assemble a tetra with the 20 cm straws and hairpins.



2. Connect mid-points with hairpins and the 10 cm straws.



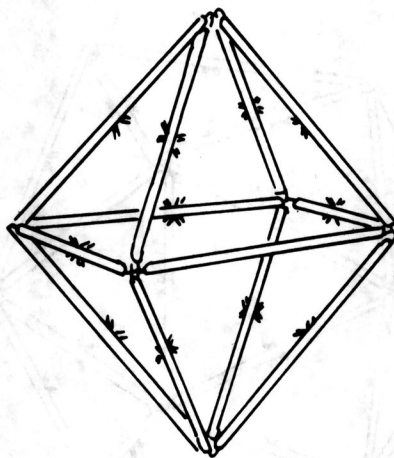
3. What did you create?



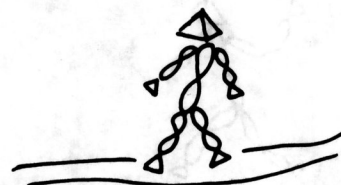
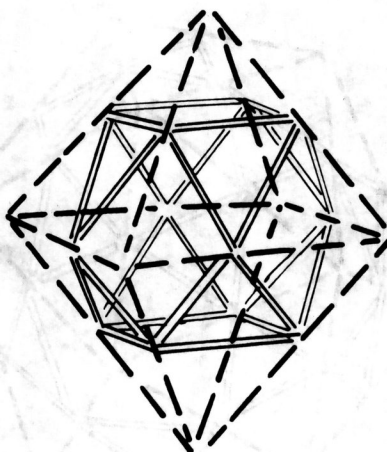
ACTIVITY 24
START WITH AN OCTAHEDRON AND DO THE SAME THING:
WHAT HAPPENS?

Materials: Twelve 20 cm straws; twelve 10 cm straws (A different color if possible); hairpins.

1. Assemble the 20 cm straws into an octahedron.



2. Connect the midpoints with the 10 cm straws.



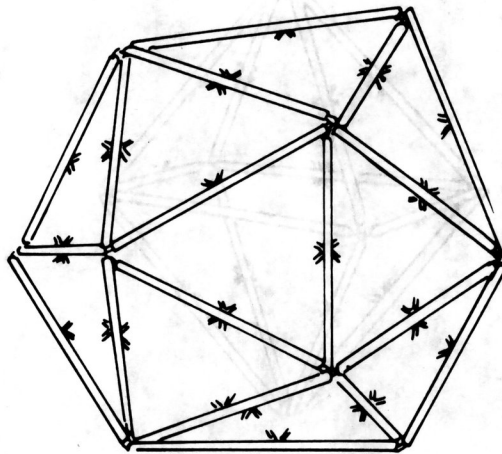
3. What did you create?

ACTIVITY 25

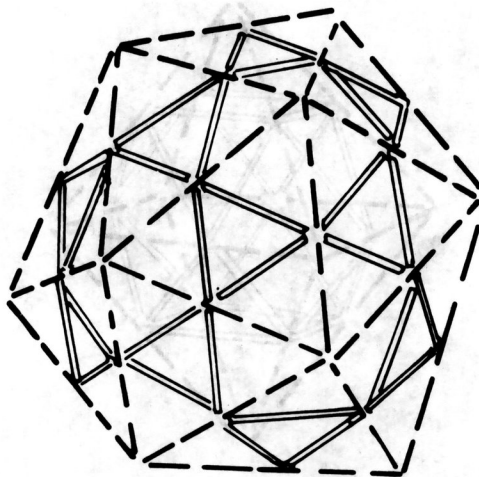
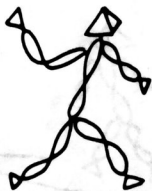
START WITH AN ICOSAHEDRON; WHAT DO YOU GET ?

Materials: Thirty 20 cm straws; thirty 10 cm straws; hairpins.

1. Assemble the 20 cm straws into triangles into connected triangles with five triangles at each vertex to form an icosahedron.



2. With 10 cm straws, connect midpoints of the sides.



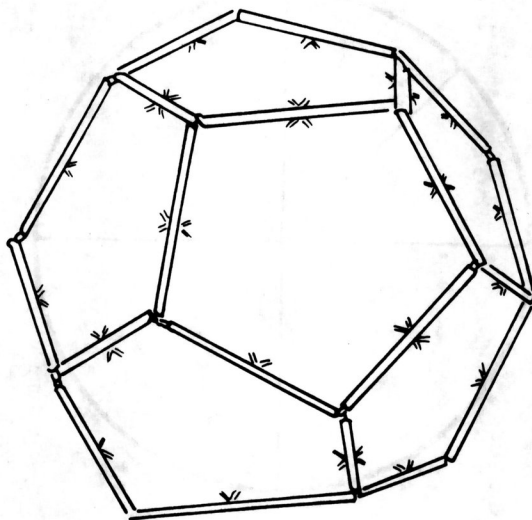
3. What inner figure did you create? An icosadodecahedron. (A very large figure!)

ACTIVITY 26

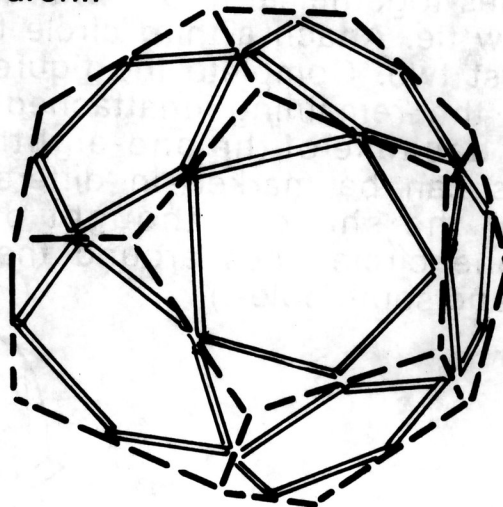
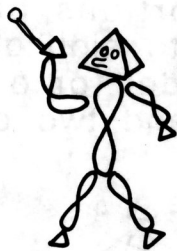
START WITH A DODECAHEDRON; WHAT WILL YOU GET ?

Materials: Thirty 10 cm straws; thirty 7 cm straws; hairpins; mattress needle and thread.

1. Assemble 10 cm straws into pentagons, connecting three pentagons at each vertex. It will not be rigid, so work with a friend. This works best if you use the needle and thread to form the dodecahedron.



2. Connect the midpoints with 7 cm straws.
another icosadodecahedron!!



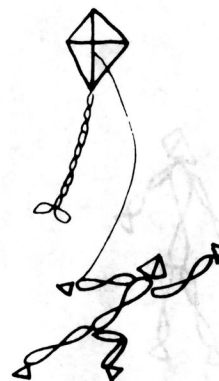
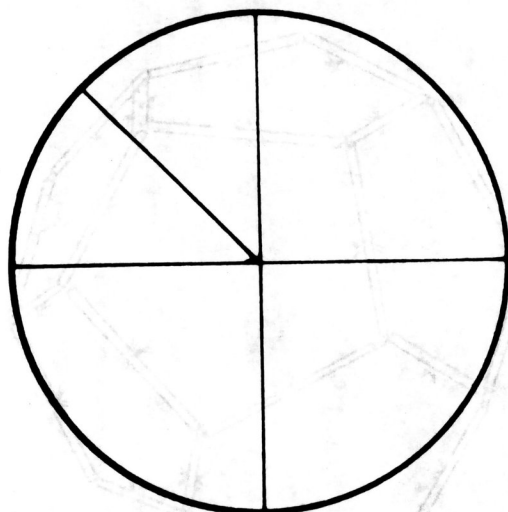
3. Does it become rigid? Why?

ACTIVITY 27

CAN YOU CREATE A SPHERICAL OCTAHEDRON WITH FOUR CIRCLES ?

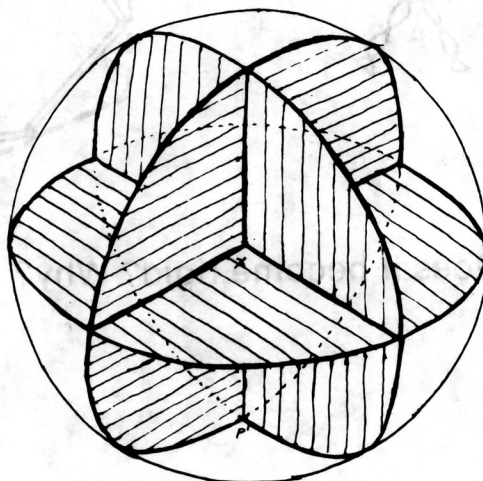
Materials: Scissors; four circles; glue; bobby pins.

1. Fold each circle into fourths.
2. In one of the fourths, make another fold from the center out. This makes sectors that are each one-eighth of a circle.



3. Bring together the one-eighth sectors and fold them behind one of the one-fourth sectors. Glue in place. All three one-fourth sectors are mutually perpendicular.

4. Fasten two circles together at a fold with a bobby pin. The figure will look like a bow tie. Attach a third circle to one unattached fold on each of the first two. Complete the figure by attaching the last circle to each of the remaining unattached folds. (This is not a symmetric figure because of the one-eighth folded portions, but three great circles can be marked in different colors to highlight their positions. If the shape is thought of as a model for our spherical earth, one circle goes around the equator and two go through the north and south poles.)

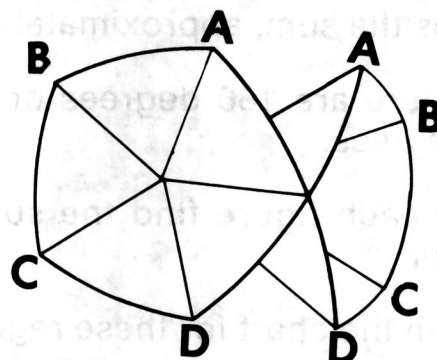
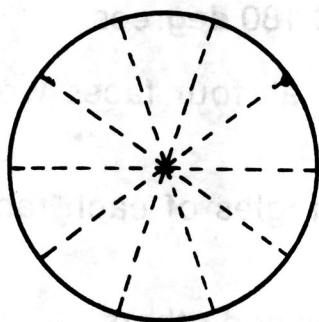


ACTIVITY 28

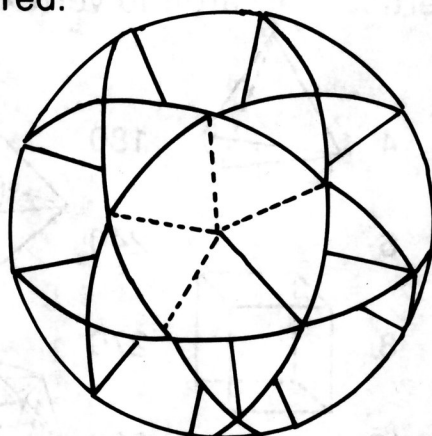
SIX PENTAGON BOW TIES; WHAT DO THEY FORM ?

Materials: Six circles; a supply of bobby pins.

1. Fold each circle in half; then fold the halves into fifths or 36 degree angles, as pictured.

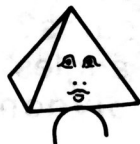


2. Using opposite radii, fasten with a bobby pin to make a bow tie. Label the folds as pictured.



3. Match folds B and C on one bow tie to both A's or both D's on another bow tie and fasten with bobby pins. Continue to build, always attaching B and C from one bow tie to either both A's or both D's on another bow tie.

4. Outline and count the great circles; these are great circles of an icosahedron.



SYNERGETICS, Pages 178 and 189 give patterns for more complicated models.

ACTIVITY 29

WHAT IS ANGULAR TOPOLOGY ?

Materials: As many as possible of the solid figures already assembled or any other set of polyhedra, including at least one tetra; protractors for measuring angles.

1. Measure with a protractor the angles on each face of the tetra. What is the sum, approximately. ALWAYS 180 degrees.
2. If there are 180 degrees on one face, all four faces would sum to 720 degrees.
3. For each figure find the sum of the angles of each face, and add them up.
4. Fill in the chart for these regular figures; add others.

Polyhedron	Column 1 # of vertices	Column 2 Sum of angles around vertex	Product Multiply Divide column 1 by by 720 column 2	
Tetrahedron	4	180	720	1
Octahedron	6	240	1440	2
Cube	8	270	2160	3
Icosahedron	12	300	3600	5

Always divisible by 720 !!!! Does it work for other solids?

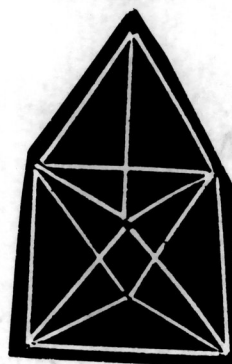
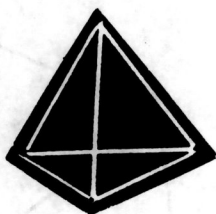
Try the vector equilibrium, the half octa, the one-fourth octa, the one-fourth tetra, the one-eighth octa, the rhombic dodecahedron. (HINT: You may have to measure and add up angles around vertices that have different sums? Why do you think it works? REMEMBER: The sum of the angles of a triangle is 180. All these figures have faces that are polygons that can be separated into triangles.)

ACTIVITY 31

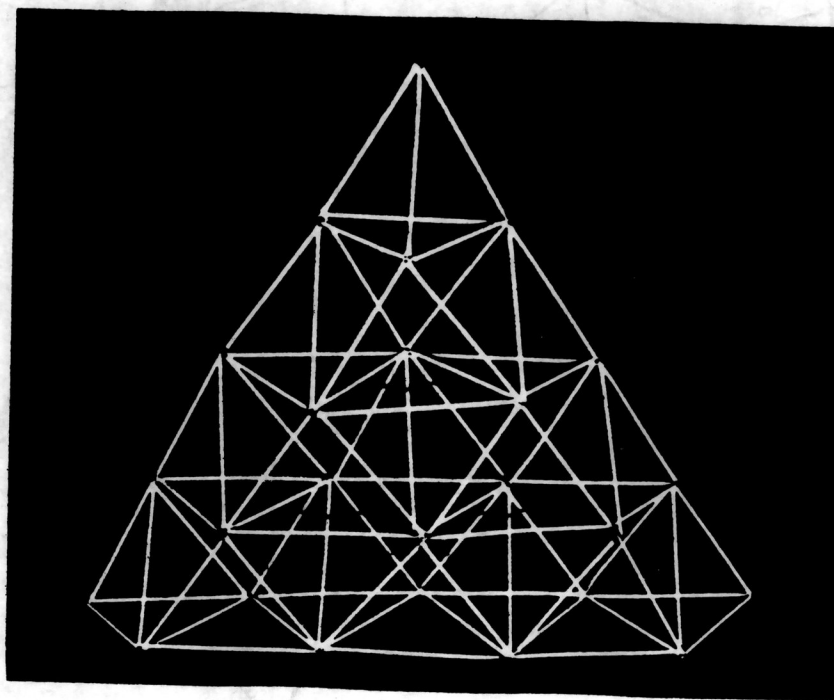
WHAT IS AN OCTAL TRUSS ?

Materials: Gumdrops; toothpicks (colored ones are more fun).
Hairpins

1. Use 12 toothpicks and 6 gumdrops to form an octahedron. Add tetras to three alternate faces of the octahedron.
2. Extend the truss by adding alternate octas and tetras. (Between each two octas is a tetra, and between each two tetras is an octa.)



3. Can you explain why such structures would be rigid?

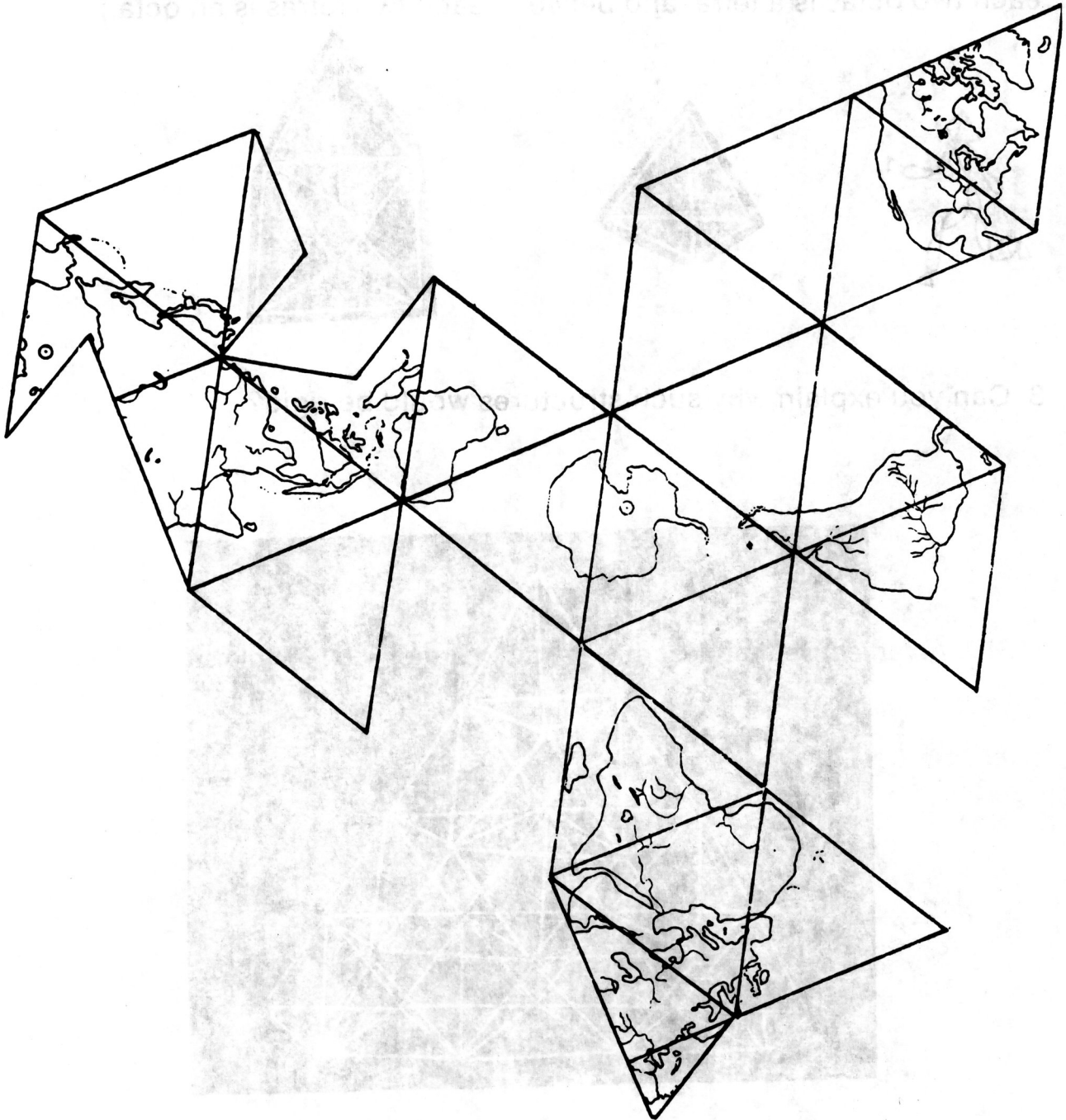


ACTIVITY 32

MAKE A MODEL OF SPACESHIP EARTH

Materials: Pattern below.

The world is less distorted when put onto an icosahedron. Cut out the pattern, and assemble it as a globe.



GLOSSARY for BUCKY FOR BEGINNERS

CUBE. A regular polyhedron with six square faces.

DODECAHEDRON. A polyhedron of twelve faces. If regular, it is one of the five Platonic Solids.

FREQUENCY. As Bucky uses this term, the number of linear units per edge.

GEODESIC DOME. A structure of struts usually triangular in shape that supports itself without inner posts.

HEXAGONAL NUMBERS. 1, 7, 19, 37, ...(See page 37). **HEXAGON.** A six sided polygon.

ICOSADODECAHEDRON is a polyhedron of 20 equilateral triangles and 12 pentagons, no two of the same sharing an edge.

JITTERBUG. As Bucky uses it, a particular arrangement of 24 dowels and their connectors. It forms an outer shape of the vector equilibrium, if supported. (See page 31)

OCTAHEDRON. A polyhedron with with eight faces. If regular, it is one of the five Platonic Solids.

OCTAL TRUSS. A configuration of tetrahedra and octahedra that create a very rigid structure.

RHOMBIC DODECAHEDRON. A polyhedron with twelve rhombi for faces. It is a cube turned inside out.

RIGID. An adjective that describes a stable or non-collapsible structure.

SPHERE. The set of all points equidistant from a center point.

STELLATE. To build a pyramid on the faces of a polyhedron.

SYNERGY. The energy exhibited by things working together that is not a part of the separate components. (See quotation, page 2.)

SYSTEM. As Bucky describes it, four (or more) non-coplanar points, the inside, the outside determined by those points.

TANGENT. Touching in one point.

TETRAHEDRON. Polyhedron with four faces. If regular, it is one of the five Platonic Solids.

TETRAHELIX. Twenty tetrahedra glued together so the edges form a helix.

TEACHER NOTES

The instructions in this book are explicit enough for fourth graders or older students to make and enjoy the structures. Even the older students should have the experience of making the models before they pursue other investigations about them.

However, almost every activity is loaded with underlying principles of mathematics. A teacher can use these as a starting point for much more sophisticated mathematics, if students are at the level to understand and enjoy the investigations.

These "Teacher Notes" have two purposes. First, they point out mathematical concepts inherent in the activity; second, they ask questions that will make students use their mathematics to answer intelligently.

ACTIVITY 1. Make a Dome in Bucky's Memory, Page 4.

The instructions demand that each shape result in a triangle, except for the base. Students will enjoy creating more complicated ones.

ACTIVITY 2. What is a System? Page 5.

It is important to create a sense of fantasy in the students. This will lead them to imagine these ideas before they have had formal geometry. Don't tell them; let the fantasy lead their imaginations.

All points at a distance equal to or less than a radius determine a sphere and its interior.

All points equidistant from two fixed points lie on a plane that bisects the line between those fixed points. The locus of points equidistant from three non-collinear points is a line perpendicular to the plane determined by the three points.

Four points, one not in the plane of the other three, determine a tetrahedron. There is exactly ONE point equidistant from those four points.

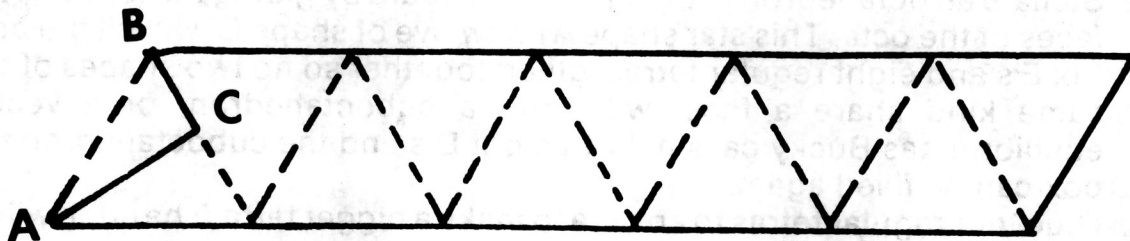
Bucky defines a system to consist of at least six parts: four points as described above, the space outside that tetrahedron, and the space inside that tetrahedron.

In TETRASCROLL, Bucky tells his daughter the story of the three bears. The story began when she was very small. As she grew, it evolved into a more complex version through which he explained the universe and how it worked. This "What is a System" is as he told it in the early years. The three bears are three non-collinear points, and Goldy is the fourth point in a plane apart from the plane determined by the three bears. These four points are the first four parts of a system. The points inside are the fifth part and the points outside are the sixth.

ACTIVITY 3. How Can You Fold a Tetrahedron? Page 7.

These formal theorems of geometry can be experienced and noticed as students follow the instructions and make observations.

Three parallel lines cut equal segments on every transversal. Hence, in the first fold $BC = \frac{1}{2} AB$.



Angle C is a right angle; therefore, Angle B = 60 degrees, since a 30-60-90 triangle is determined if one leg is half the hypotenuse. Five triangles fold in one direction to make the tetra, while the other five fold the opposite way to make it more rigid. Triangle 10 tucks inside.

ACTIVITY 4. What is Volume in Tetra Units? Page 9.

This is purely a model making activity from which volume by filling and pouring is inferred. The unit of measure is the regular tetrahedron. The key observation is that B and C are two tetras with equal bases and altitudes, hence equal volumes. Students need to check by filling.

An octahedron is a solid figure with eight faces; the model is for a regular octahedron.

The activity uses patterns for fractional parts of the octahedron and leads students to measure those in terms of a regular tetrahedron as a unit of one.

Relationships in terms of the regular tetra as a volume unit are:

Octahedron = 4 tetras

Half-octa = 2 tetras

Irregular tetra (that is $\frac{1}{4}$ an octa) = 1 tetra

One-eighth octa = $\frac{1}{2}$ tetra

The relationships sought here are simple; advanced students who work from formulas of volume based on cubic unit measure will appreciate this more direct way of inferring. Bucky claimed that all polyhedra could be measured integrally using the tetrahedron as a unit. He claimed that our three orthogonal axes are merely a convention, that resulted in our needing irrational numbers.

ACTIVITY 5. What is the Volume of the Cube? Page 15.

Cube volume is discovered in terms of the parts discussed above. With tetra B as the unit, the small tetras D are $\frac{1}{8}$ octas, hence $\frac{1}{2}$ in terms of B. This observation makes the conclusion that the volume of the cube is 3 in tetra units

simple. Extend this puzzle format to making eight small cubes by the pattern and then making an open box to hold them. The edge of the box should be longer than 10 centimeters so the cubes will fit in easily. Let students create their own open box to fit.

The ways of filling the box are many. Here are a few:

- a. Stellate an octahedron with regular tetrahedra by gluing the tetras to the faces of the octa. This star shape with twelve of shape C, will fill the box.
- b. Six E's and eight regular tetras, glued together so no two shapes of the same kind share a face, will form a cuboctahedron, or a vector equilibrium as Bucky calls it. With eight D's and the cuboctahedron the box can be filled again.
- c. Glue four regular tetras to an octa to make a bigger tetra. The edge will fit into the diagonal of the box's base. To fill the four empty regions, use three D's and a regular tetra for each of the spaces.
- d. Many more can be found.

ACTIVITY 6. Stellate an Octahedron: What Do You Create? Page 17.

The students need to verify that four of the figure made with the pattern will form a regular tetra. The figure that results from stellating the octa is a rhombic dodecahedron. Its faces are rhombi (parallelograms with equal edges).

ACTIVITY 7. What Is the Volume of a Two Frequency Tetra ? Page 19.

This entire activity constitutes experience with dimensionality for one, two, and three dimensions.

Students discover by building that the volumes of the "growing" tetras are the cubes of the frequency.

"Frequency," as Bucky uses it, is the number of linear units along each edge, no matter what kind of solid figure is "grown." This use of "frequency" is entirely different from the meaning in terms of physics.

The ratio of edges (or frequencies) squared is the ratio of the surface areas. (2-D)

The ratio of the edges (or frequencies) cubed is the ratio of the volumes. (3-D)

ACTIVITY 8. How Many Spheres Pack around a Central Sphere? Page 21.

Outlining around the pins with dark thread emphasizes the formation of a shape resembling a vector equilibrium or cuboctahedron, which will appear in many other activities of the book.

The number of tangent spheres about a central sphere is 12 for the first frequency. ($10 F^2 + 2$) For frequency of two the number of spheres in the outside layer = $10 \times 4 + 2 = 42$; for third frequency = $10 \times 9 + 2 = 92$, etc

ACTIVITY 9. What Is the Volume of a Vector Equilibrium? Page 23.

Volume of vector equilibrium found by summing assembled parts:

8 tetras	= 8
6 half octas	=12
TOTAL	=20 if tetra =1

ACTIVITY 10. Can "Bow Ties" Make a Vector Equilibrium? Page 25.

Four great circles folded into six parts and made into bow ties will form a vector equilibrium around which four great circles can be outlined. (Or four hexagons can be outlined.)

ACTIVITY 11. 1 and 1 = 4? When? Page 27.

Synergy is the energy exhibited when several objects together have characteristics or power not found in the separate parts.

ACTIVITY 12. Does 2 and 2 = 8 ? When ? Page 29.

Here's another example of synergy, when four cardboard triangles or four pipe cleaners make eight triangles.

ACTIVITY 13. Can You Make a Cube Rigid? Page 30.

A rigid figure does not move or collapse; triangles make figures rigid; alloys are stronger than pure metal, because there are two tetras intersected for strength.

ACTIVITY 14. How Do Gases, Liquids, and Solids Move? Page 32.

These simple activities resemble the movements, indicated in a style that students appreciate.

ACTIVITY 15. "Unzip" a Tetrahelix: What Does It Form? Page 34.

Twenty bonded tetras form the tetrahelix, which is a model of DNA. The helix lacks a little over 7 degrees of being a complete turn of 360 degrees. One finds the same lack as five tetras are put together about a point; hence regular tetras DO NOT make an icosahedron.

The jacket for the tetrahelix is a simple grid of equilateral triangles. Discovering this fact made writing the whole book worth the trouble!

ACTIVITY 16. What Can a Jitterbug Form? Page 35.

The jitterbug demonstrates synergy in a way that captures the fancy of young and old. It makes many figures.

(NOTE: At Nueva Learning Center, we have a jitterbug made of 4 foot poles. Synergy is truly at work, as at least four children are required to set it up and enjoy it.)

ACTIVITY 17. How Can Spheres Form a Tetra? Page 38

The understanding here of the sixty degrees between the line of centers is important as students move to the next puzzle. There the angle between the line of centers is 90 degrees, which demands that the spheres lie in two different planes.

Triangular numbers appear in many areas of mathematics, and this is an easy introduction.

ACTIVITY 18. Can You Solve This Tetra Puzzle? Page 39.

This puzzle is difficult, but as Bucky says, "...it's well to remind everyone at the onset that we only can get from here to there by a series of mistakes..." Tetrascroll, xxi

ACTIVITY 19. Bucky's Favorite Puzzle. Page 40.

This was one of Bucky's favorites. Using the same concept of two pieces, he made a much larger tetra, of about frequency 10.

ACTIVITY 20. How Can You Grow Hexagonal Numbers? Page 41.

Hexagonal numbers can be "grown" from hexagons, tangent circles, or balls arranged in the plane.

ACTIVITY 21. Tetrahedral Volume and Hex Numbers. Page 42.

The volumes of the layers of a four frequency tetra are the first four hex numbers..1, 7, 19, 37.. The sum of the first two hex numbers is two cubed; the sum of the first three is three cubed; the sum of the first four is four cubed.

ACTIVITY 22. How Can a Cube Create a Vector Equilibrium? Page 43.

A cube with the midpoints connected is a vector equilibrium, often called a cuboctahedron. Ask questions such as: How long is an edge of the cube? (20 cm) How long is the straw that connects the midpoints? (Pythagorous again! Also, a line joining the midpoints of two sides of a triangle is parallel to the third side and equal to half the third side.)

ACTIVITY 23. How Does a Tetra Relate to an Octa? Page 44.

The results are surprising, and many in-depth questions of volume and area can follow.

Have students note the number of straws needed to make the octahedron; the number needed to join the edges; and the type of polyhedron created. Again, all the volume and surface area questions are worth pursuing.

ACTIVITY 24. Start with an Octa; What Do You Get? Page 45.

Compare the results here, in numbers of straws needed and resulting figure. It is an icosadodecahedron. Why is it this way?

ACTIVITY 25. Start with an Icosahedron; What Do You Get? It is an icosadodecahedron. The figure is large but manageable, because the triangles needed to make the icosahedron maintain a more rigid figure.

ACTIVITY 26. Start with a Dodecahedron; What Do You Get? Page 47.

The first time I made this I used 20-cm straws; it was enormous and hard to handle. Two people are definitely needed even with the shorter straws. Using a mattress needle and thread to make the dodecahedron results in a more permanent figure. Using hairpins to put on the straws joining the midpoints works well. The new figure is another icosadodecahedron.

ACTIVITY 27. Can Three Great Circles Fold an Spherical Octahedron? Page 48.

Using the folded circles this way to make an octahedron creates the orthogonal xyz-axes. Therefore, it is not Bucky's favorite shape, nor is this version a symmetrical one. But, I think it is valuable in the sequence. It CAN be used as a model for the three-dimensional xyz-coordinate system.

ACTIVITY 28. What Do Pentagonal "Bow Ties" Create? Page 49.

Here is another paper folding activity that allows students to examine circles of rotation of symmetric parts of an icosahedron. The outer assembly is of pentagons and triangles, no two of the same adjacent. Outlining great circles results in five. Ask, "What opposite vertices or mid-points of either faces or edges can you hold, as you rotate an icosahedron to create these five circles?" The outline of twelve pentagons and twenty triangles is another icosadodecahedron.

ACTIVITY 29. What Is Angular Topology? Page 51.

The results, including the formula are easily verified if students understand that the sum of the angles of a triangle is 180 degrees.

ACTIVITY 30. What Is an Octal Truss? Page 52.

It seems necessary to point out what an octal truss is and how structures can be made strong using it. Its structure is basic to the domes that Bucky was most famous for creating.

ACTIVITY 31. Make a Model of SPACESHIP EARTH!! Page 53.

Bucky published many different projections of the globe on polyhedra. Since the regular icosahedron is an important solid to handle and know, it seems fitting to include this activity. It agrees with his efforts to make models that more accurately resemble the real world. I hope this will remind the students of SPACESHIP EARTH, as Bucky described our planet.

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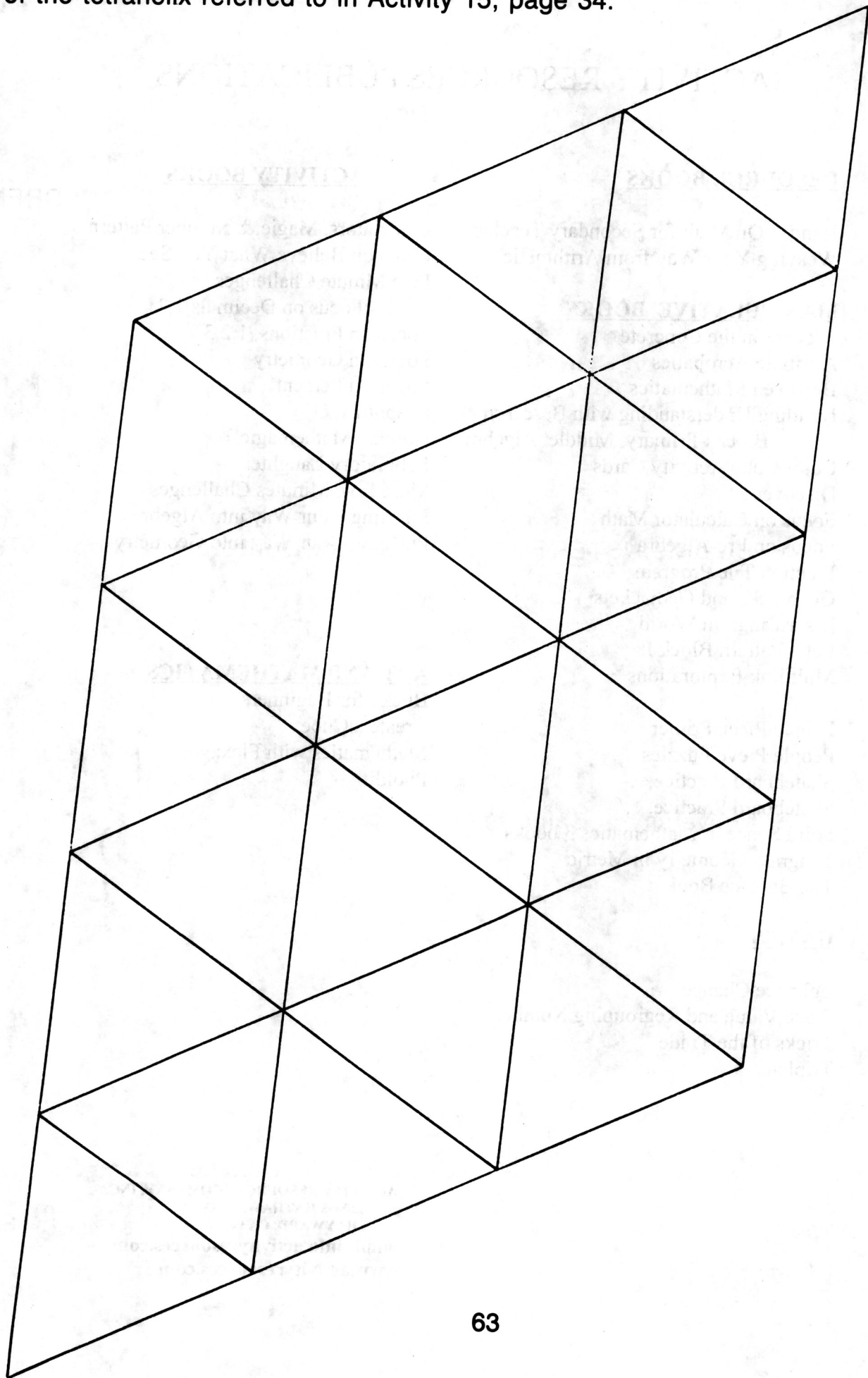
MATERIALS ESSENTIAL FOR EACH ACTIVITY

ACTIVITY	MATERIALS
1, 30	Gumdrops and toothpicks
2	String and a ring
3	Strips of paper
4, 5, 6, 9, 22	Push pins, construction paper, scissors, glue
7	Sugar cubes, materials in 4
8	Styrofoam balls, pins, thread
10, 27, 28	Four circles, bobby pins
11	Pipe cleaners
12	Four cardboard triangles, 6 pins, straws, hairpins
13	Hairpins, straws
14	Same as 4
15	Dowels, surgical tubing
16-19	Styrofoam balls or marbles, pins or cement
21	Paper from page 63
23-26	Straws, hairpins
29	Protractors, solids from other lessons
31	Pattern and scotch tape

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Make three copies of these and glue them end-to-end to make the jacket of the tetrahelix referred to in Activity 15, page 34.



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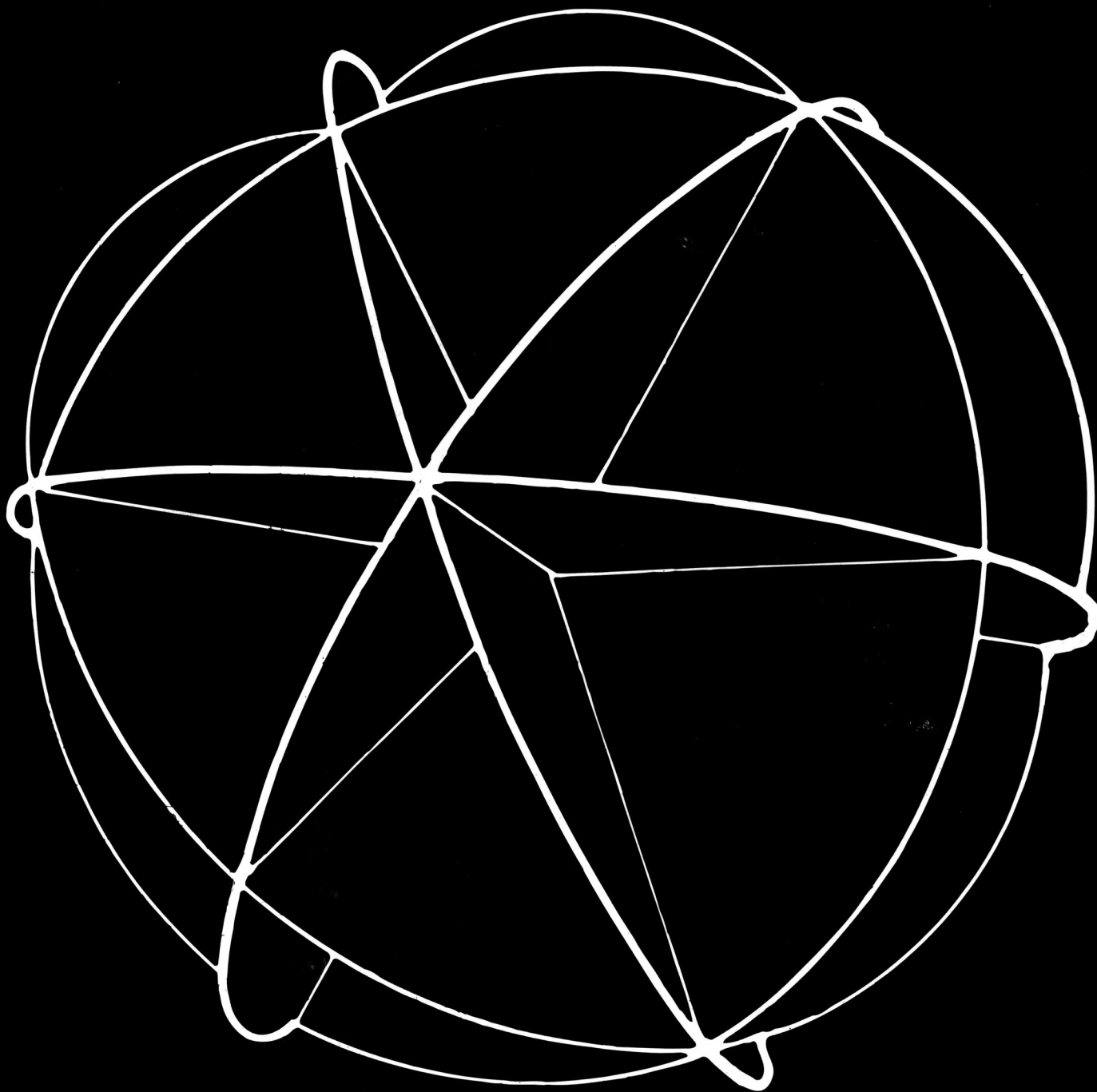
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